JIGS AND FIXTURES
FOR MASS PRODUCTION

by LELAND A. BRYANT
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To Joe

PREFACE

THE PURPOSE of this book is to provide comprehensive and authoritative information regarding those manufacturing tools that are collectively known as *jigs* and *fixtures.*

The text has been so prepared that it will be understandable both to the beginner and to the expert. Moreover, to make certain that the various terms used can be fully understood by the lay reader, the authors have provided a complete glossary to supplement the text.

The authors have endeavored to omit controversial details that might impair the value of the book for the expert. However, since almost every tooling principle and method may be open to controversy, it must be noted that they have recorded only those things that have been definitely tried and proved satisfactory.

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of comparatively good quality and sell for a low price—especially if it is to compete with similar products on an open market.

(2) *The desired or required rate of production.* If very many articles are to be produced in a short period of time, a large number of

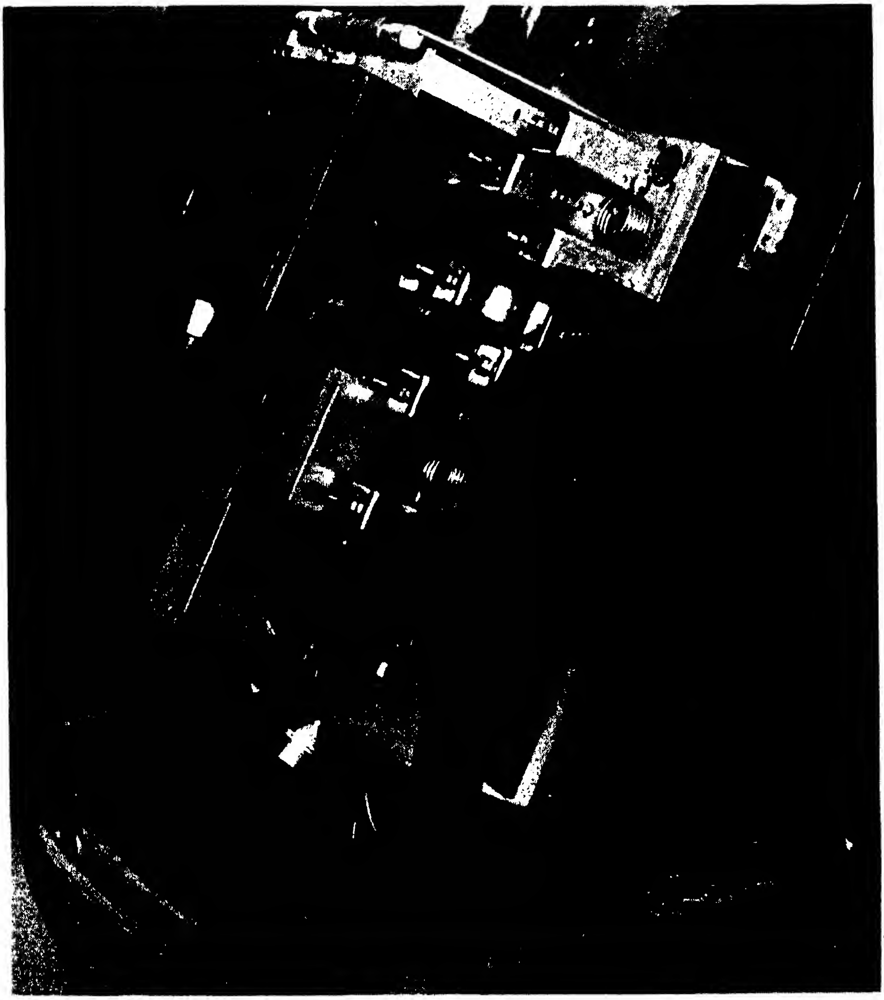


FIG. 1. A General-purpose Fixture.

special tools (such as jigs and fixtures) can be used because they will pay for themselves by saving time. Special tools are not widely employed in small-scale manufacturing because they cannot be used in producing a variety of articles and their initial cost is greater than the cost of the time they can save.

(3) *Materials to be used.* Manufacturers could not, in constructing plywood airplanes, use the same type of tools that would be used in building a steel locomotive. Therefore, it can be logically concluded that materials to be employed in the manufacture of a product primarily determine the nature of jigs and fixtures.

(4) *Number and size of component parts.* Naturally, the number and size of component parts affects the number and size of tools that

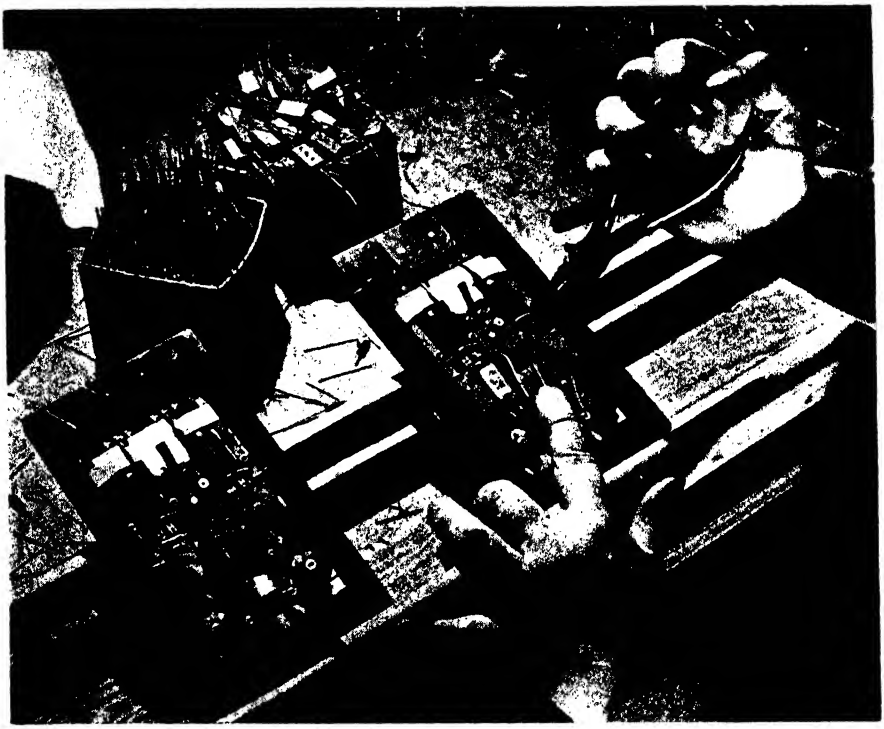


Fig. 2. A Small Jig.

must be utilized in manufacturing a product—depending, of course, on the desired rate of production.

(5) *Quantity to be manufactured.* If only a small number of articles are to be manufactured, it is generally practical to use cheap or short-lived tools. Such tools are often expensive in mass production, because their cost is increased each time they must be replaced before the job is complete.

(6) *Dimensional tolerances.* As a rule, it is easier to manufacture a product whose dimensional tolerances are comparatively large; and sometimes it is possible to utilize components which vary considerably

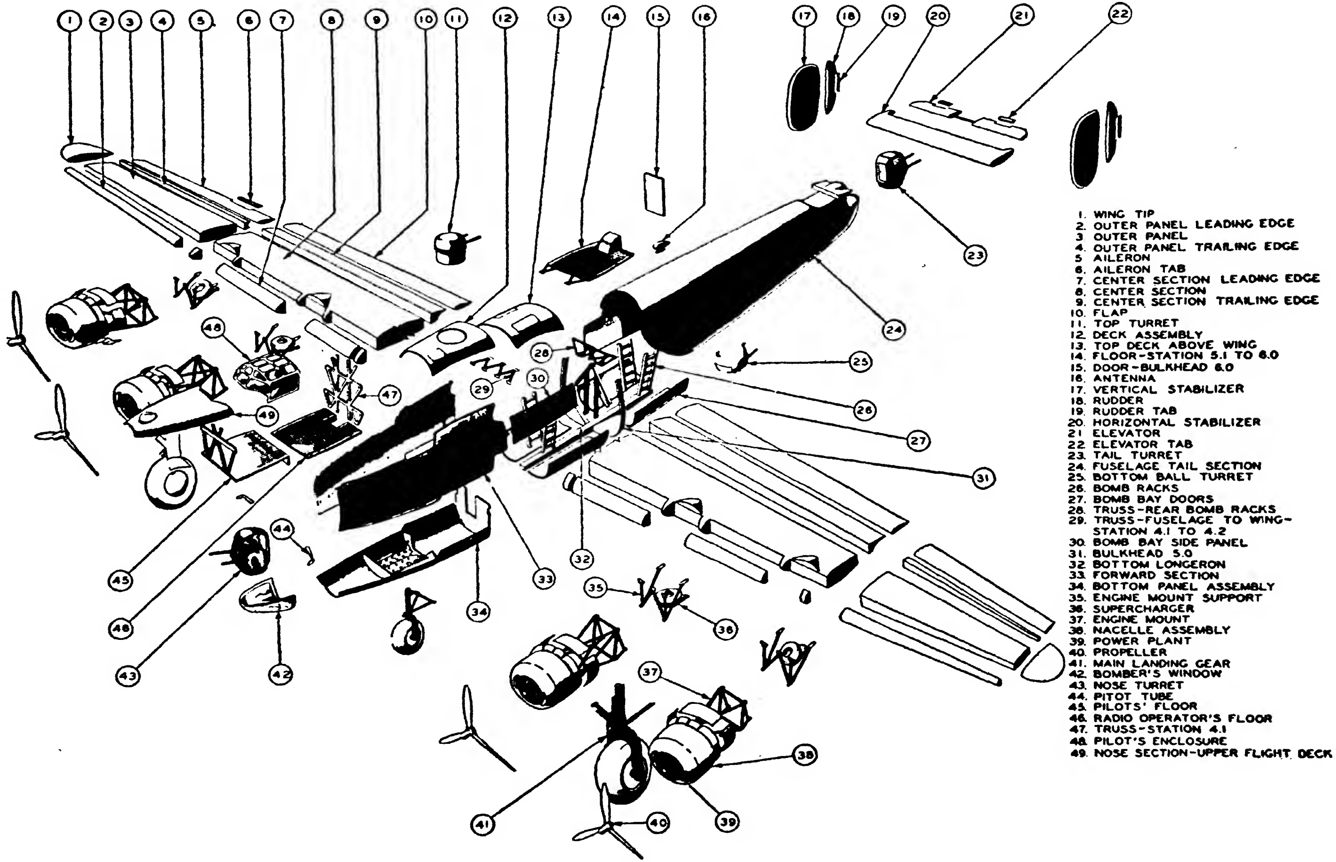


FIG. 3. An Ideal Airframe Manufacturing Breakdown.

from the design dimensions. However, if the components of the product must be interchangeable, very accurate jigs and fixtures must be constructed—the degree of accuracy depending on the nature of the product. In mass production, the ideal condition would be to have 100 per cent parts interchangeability, but to date the costs of extremely accurate tooling have made this generally prohibitive.

(7) *Tooling and assembly release times.* The time required for tooling and the time required for assembly must be balanced, in order to produce an article when it is needed and not three or four months too late. Manufacturers usually set up and endeavor to follow release dates; and, since speed is the keynote of modern industry, every effort is made to design tools which will speed production. Simple tooling may be satisfactory, or complex jigs and fixtures may have to be used. The jobs of planning, designing, and fabricating tools take time. Therefore, to get into production quickly, it is sometimes necessary to start out by using both experimental and regular production tools.

(8) *Design and manufacturing breakdown of the product.* In mass-producing large machines such as airplanes and automobiles, it is especially desirable to have a product designed for maximum ease of manufacture and maintenance as well as for optimum performance. Proper designing makes it possible to break the product down into numerous small and simple parts, which can be assembled simultaneously over a wide area by a large number of workers with limited skills. An "ideal" airframe breakdown is shown in Fig. 3. Complete breakdowns of this type are not always practical because they necessitate comparatively simple structures and elaborate layouts of jigs and fixtures. For efficient line production, the extent of the assembly breakdown varies inversely as the given time cycle per completed unit. For example, if the manufacturing schedule requires one completed unit every three hours, this time cycle is the maximum allowable time for each operation (including loading and unloading of jigs and fixtures). Moreover, when the breakdown is such that no single operation exceeds three hours, no further breakdown should be made because this would only increase tooling costs.

(9) *Factory space available.* No efficient manufacturing program can be carried out without an adequate area in which to get the work done. If the parts of the product are to be made in a number of factories, rather than in a single plant, steps must be taken to insure good co-ordination, which is vital in attaining parts-interchangeability features. Therefore, master tools are constructed. Master tools are patterns; from them, production tools may be duplicated. If the masters are not extremely accurate, the jigs and fixtures they produce will not

be suitable for the assembly or fabrication of interchangeable parts. Because they are very expensive and hard to construct, master tools are generally used only when production requirements are extreme, as in the manufacture of aircraft in time of war.

CHAPTER 2

TOOLING PROCEDURES

Co-ordination

IN VERY small concerns it is sometimes possible for a single man to have direct control over all the work connected with designing, tooling, and manufacturing a new product. Moreover, because each and every job can receive equal and impartial consideration in a one-man organization, it might be said that a very small factory is ideal from the standpoint of possible production efficiency. But unfortunately, the output of even the most energetic individual is limited.

Therefore, in order to achieve mass production, we have manufacturing organizations made up of thousands of men—each of whom must concentrate on a single job. And since no two men have equal quotas of intelligence and ability, we find that even the best of large factories are characterized by a certain lack of co-ordination.

This lack of co-ordination is most noticeable in the tooling department, because here the more or less impractical dreams of the designer must be converted into the realities of the assembly line; and if the tooling department cannot solve the problems thus presented, the entire manufacturing program is likely to fail.

It is the purpose of this chapter to show how a high degree of co-ordination has been attained in the tooling departments of some of America's larger and more successful manufacturing concerns. In order to understand the organization involved in the following discussion, the reader will find it helpful to refer frequently to Fig. 4.

Preliminary Work

When the management of a large concern decides to manufacture a new product, the engineering department prepares what is known as a *preliminary design.* Then, to determine whether the product can be manufactured with reasonable efficiency in accordance with the preliminary design, the engineers hold a conference with the factory's tooling and production experts.

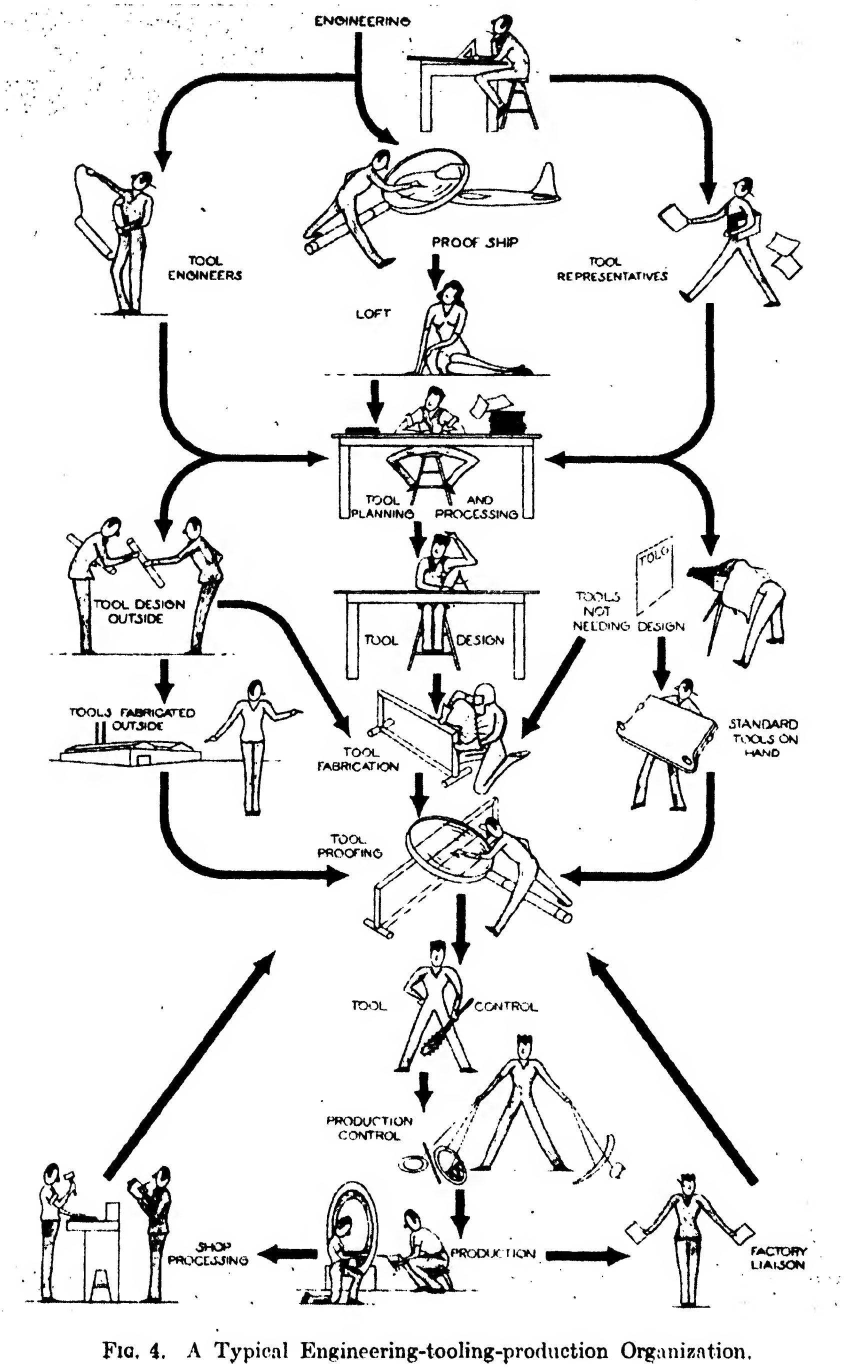


FIG. 4. A Typical Engineering-tooling-production Organization.

Perhaps a tooling representative will show how a part can be revamped so that it can be readily assembled in a general-purpose fixture; or perhaps a production man will suggest methods of simplifying the structure so that a considerable part of the manufacturing can be accomplished by unskilled labor. Consequently, compromises are made.

Engineering considerations come first, because obviously any product must be of a certain quality in order to find a market—regardless of how cheaply or efficiently it is manufactured. But, as a rule, the engineers discover that they can make concessions to both tooling and production without seriously impairing the quality of the proposed article. Then detail design drawings are made and experimental construction work begins.

Planning

If there is a great rush to get into production, *planning* may begin with preliminary design. However, since preliminary designs are usually subject to numerous changes, it is most economical to start this work after the detail design drawings have been made.

Planning is the business of creating a production breakdown and establishing the sequence of manufacturing operations. This may be accomplished with a layout, such as that shown in Fig. 5, or with a production illustration, a part of which is shown in Fig. 6. It consists of determining the number of component tools and parts that will be

CONVAIR MACHINE SHOP

Operation and Tool Layout Sheet		Part Number: X-477	
Description: Bracket	Model: 199	Material: Steel	Date: 9/2

Oper. No.	Operation	M/C Sym.	Dept.	Approx. Time		Tools, Gages
				Hr.	Min.	
1	Mill flat face, one side (cutting feed 6" per minute)	VMC	KLM		2	Fix. 901
2	Drill, ream, & face, complete	RDC	KLM		5	Jig 440-A
3	Bore 4" dia. two cuts (220 RPM feed, 32" per min. roughing, 40" per min. finishing)	CMA	N		1	Fix. 706
4	Burr and stamp	SLA	KLM		1	

FIG. 5. A Typical Planning Layout.

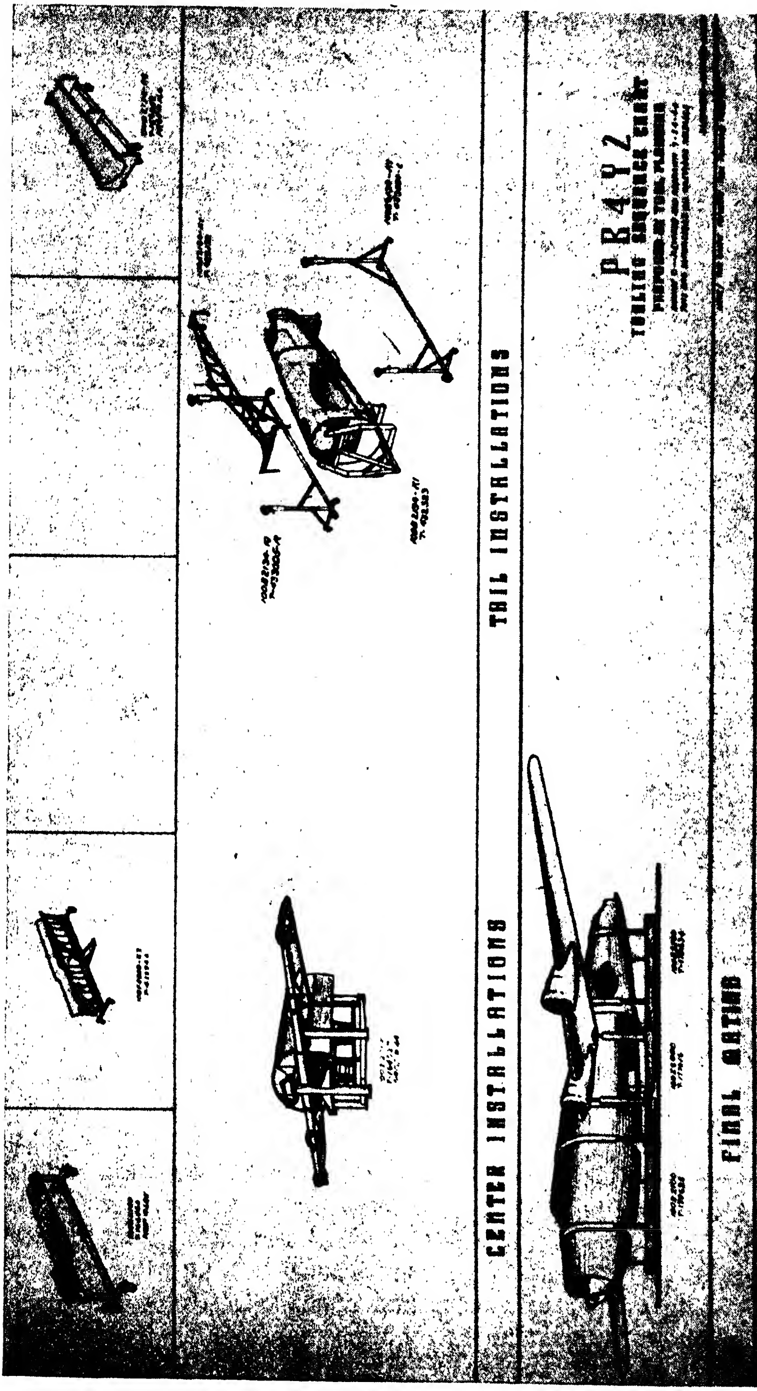


FIG. 6. A Typical Planning Production Illustration.

required, assigning numbers or identifying symbols to the tools and parts, and enumerating the steps that must be taken in fabricating the parts and assembling them into the finished structure.

Through planning, it becomes possible for a manufacturer to ascertain, months ahead of time, what will be needed and how much it will cost to manufacture a new product.

Experimental Models

Engineering science is now so exact that there is little doubt as to whether a new machine will operate; but paper work is no substitute for practical experience, and virtually every new design will have a certain number of shortcomings, or "bugs." The only way to prove the value of a proposed product is to construct an experimental model which can be tested and altered until its performance is considered adequate.

As a rule, experimental models are handmade—without the benefit of special equipment. However, if the structure involved is exceedingly large or complex, the tooling department may be called upon to produce a few *prototype* jigs or fixtures.

Special production tools are not generally used for experimental construction work, because they are expensive and because they may have to be redesigned by the time the experimental model has been tested and altered so as to eliminate the "bugs."

Tooling Department

Although it is directly related to both engineering and production, the planning group is generally organized as part of the tooling department so that its work may be closely co-ordinated with the work of the tool-design group. The jobs of planning and tool designing should be completed almost simultaneously as soon as the experimental model has been brought to a satisfactory stage of development.

Here it should be observed that the primary purpose of the tooling department is to reduce costs by insuring the type of interchangeability that permits rapid assembly and by eliminating the necessity for manual operations in production work.

Since over-all parts interchangeability would normally necessitate an expensive outlay of equipment, most manufacturers base their tooling programs on what is called the *selective assembly system.* In accordance with this system, only the more important parts of a structure are fabricated within interchangeable dimensions; all other parts are machined to greater tolerances and must be assembled by selecting components so as to attain the required fits.

Jigs or fixtures are used in modern factories regardless of whether the parts of an article are to be interchangeable, because it has been found that these tools can be employed to speed production and lessen the need for skilled workmen as well as to promote dimensional uniformity.

"Tooling Up"

The term *tooling up* is generally used by manufacturers to denote the actual work of constructing jigs, fixtures, and other special tools required for the quantity production of an article; and this, of course, is directly accomplished by the tool-fabrication unit of the tooling department.

Until recently tool fabrication was a job almost as difficult and complicated as tool designing, and it was therefore necessary to employ only the most skilled craftsmen for the major portion of the work involved in building jigs and fixtures. However, because of the development of equipment such as the collimator and the master tooling dock (both of which will be thoroughly described later in this book), it is now possible to apply mass-production principles to tool fabrication by assigning various phases of the work to groups of specialized workmen. For example:

(1) A group that specializes in the cutting and making of rough jig or fixture structures.

(2) A group that specializes in the finishing of jig or fixture locators.

(3) A group that specializes in the drilling and machining of fittings.

(4) A group that specializes in the assembly of component jig or fixture parts.

(5) A group that does "pickup" work such as installing clamps, applying stencils that will identify various tools, and similar work.

Tool Proofing and Control

After a jig or fixture has been fabricated, it must be carefully inspected to determine whether it is in conformity with the requirements set forth by tool design. For this purpose, each large tooling department has a "tool-proofing" section. If the tool proofers approve the work of the fabrication unit, the jig or fixture is turned over to a "tool-control" group before it is allocated to the proper production department.

The tool-proofing and tool-control groups are closely related, and their work with regard to any one tool may continue as long as that tool is utilized by the factory.

It cannot be assumed that a jig or fixture will retain its dimensional accuracy after being moved about from place to place, or after being

subjected to the stresses caused by operations such as riveting and welding. Therefore, the proofers must re-examine the tool occasionally. To be sure that the tool is in the best possible condition at all times, the control unit must keep a record of each examination. This record is generally filed along with the tool-design drawing in order to facilitate inspection work.

Further, if the jig or fixture is not constantly employed in production work, the control unit must provide storage space for the tool when it is not in use.

Standardization

The answer to virtually every major problem presented by mass production is *standardization.* If each job in any plant can be made a simple and unvarying routine, the co-ordination so earnestly sought by all large manufacturers can be automatically attained.

Most successful manufacturers eventually manage to achieve standardization in connection with their production lines, but only a few thus far have visualized this asset in their tooling departments. The general tendency is to regard tooling as a strictly creative occupation; and, for this reason, we sometimes find that production workers on a single assembly line are obliged to build identical parts in jigs or fixtures of entirely different designs.

True enough, the work of the tool designer cannot be cut-and-dried like the work of an assemblyman; but in a factory where any individual type of article is consistently produced it is only reasonable to assume that some standardization of tooling procedures will greatly simplify the entire process of manufacturing.

For example, one large manufacturer recently discovered that his tool designers had about a dozen different methods of designing *picture-frame* fixtures, such as the one shown in Fig. 7. An investigation revealed that the method used for any one job depended largely upon the whims and fancies of the individual designer, and that consequently it was extremely difficult to standardize either tool-fabrication or production-line processes. The tool designers were called into a conference; and, after a detailed discussion, the following general specification for picture-frame fixtures was drawn up:

Each picture frame fixture will be so constructed as to form a square or rectangular frame, the work area being in and around the enclosure thus constructed. It will in all cases be fabricated by welding standard steel pipe sections, and its end profile will always resemble an inverted T—the vertical leg being one side of the picture frame, and the horizontal leg being the supporting member. There will be a horizontal supporting member at each end of the fixture, and its length will comprise the full width of the fixture.

The completed fixture will be supported by machine screws, tapped into blocks welded to the horizontal end pipes; and, while there will be five of these screws on each fixture, only three will be actually used for support—the remaining two serving as safety feet. Two of the supporting feet will be at the outer ends of one horizontal leg, while the third support will be in the center of the opposite leg (with a safety foot at each end of that leg). Each screw shall be provided with a lock nut to insure a permanent setting, and the length of any screw shall be held to a minimum—an inch adjustment being considered sufficient.

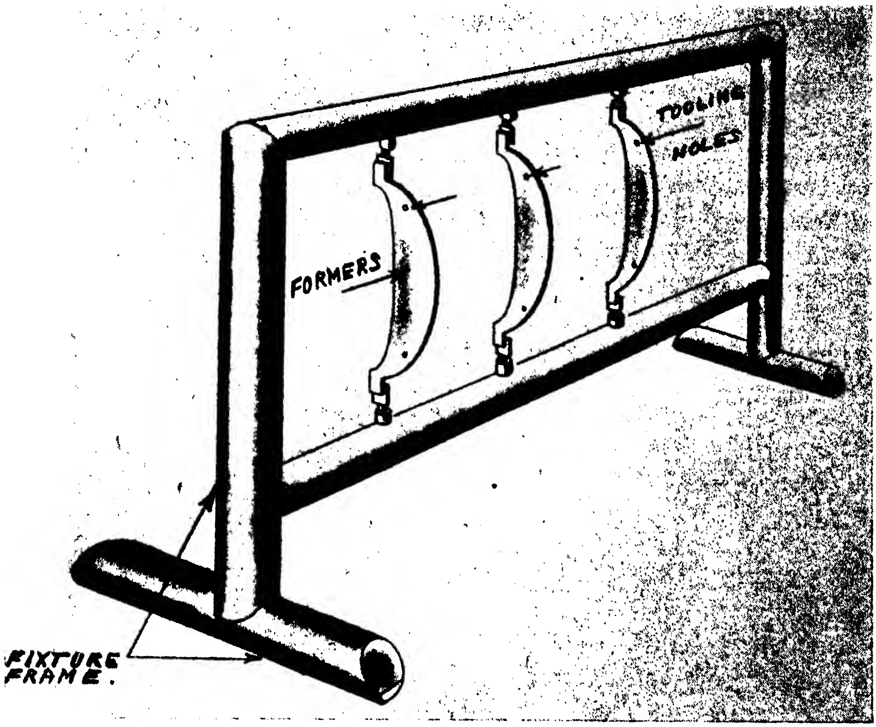


FIG. 7. A Picture-frame Fixture.

Fixtures from 216 to 288 inches in length shall have a handling or shipping break at the center, and any fixture with a length of more than 288 inches should be divided into three approximately equal segments. If a fixture is to be broken for shipping, the three-point suspension should be supplemented by an additional point of rest at each break. The coupling for each break will comprise two round steel flanges, one welded to each segment, and each pair of flanges will be held together with screws and dowels. The flange diameter should be four inches greater than the diameter of the pipe used in making the fixture.

The advantages of having standard specifications of this type are threefold:

(1) They speed the work of tool designing by making it unnecessary for the designer to use his imagination in laying out the basic structure.

(2) They simplify the work of tool fabrication and tool proofing by making it possible to standardize methods of construction and inspection.

(3) They make it possible for the semiskilled production worker to handle a variety of jobs by providing him with tools of a uniform nature which will not strain his imagination.

Engineering and Production Designs

To understand some of the problems encountered by the tooling department of a large manufacturing organization, it is necessary to understand some of the differences that exist between the ideal engineering design and the ideal production design.

For example, let us examine the shafts shown in Fig. 8. The upper shaft is an engineering ideal, designed to withstand certain stresses,

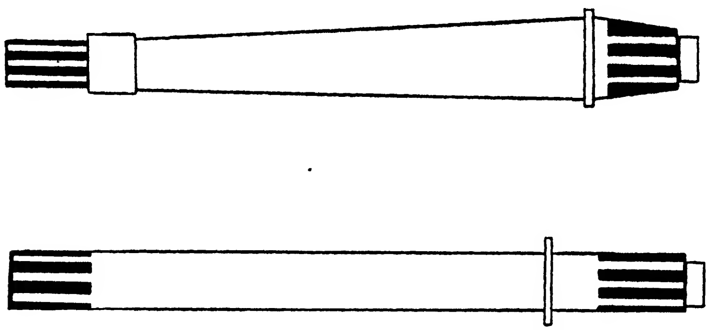


FIG. 8. Engineering and Production Designed Shafts.

while the lower shaft is a production ideal, designed to facilitate quick and economical machining operations. If the engineering-designed shaft will last three times as long as the production-designed shaft, the former should be manufactured, even though it may cost twice as much as the latter. On the other hand, if the difference in the performances of the two shafts is only slight, it would usually be impractical to produce the engineering-designed shaft, because of the difference in costs.

Besides choosing between two fundamentally good designs, representatives of the tooling department must be constantly on the lookout for flaws within the various designs. An example of this is the very poor casting design shown in Fig. 9; note that the two holes shown in line

are too far below the top face of the casting to be drilled with any degree of accuracy from a bush plate clamped above, and too close to the wall to allow room for guide bushes (which would enable them to be jig drilled).

Basic Engineering Information

The essential engineering information used in planning and tooling up for a new product is usually conveyed to the tooling department in the form of paper or metal layouts and master diagrams or tooling templates (also called *detail assembly templates*); the number of these layouts and diagrams depends upon the size and complexity of the structure to be manufactured. For example, since an airframe is a reasonably large and complex structure, let us consider the engineering information that would be passed on to the tooling department of an aircraft factory.

First of all, there would be a *master layout* in the form of an orthographic projection which would show how the component parts of the airframe are related and located with reference to the lines of a "grid plane system." As indicated in Figs. 10 and 11, the grid lines used in lofting an airframe are as follows:

(1) Station lines, which represent length dimensions.

(2) Water lines, which represent height dimensions.

(3) Buttock lines, which represent width dimensions.

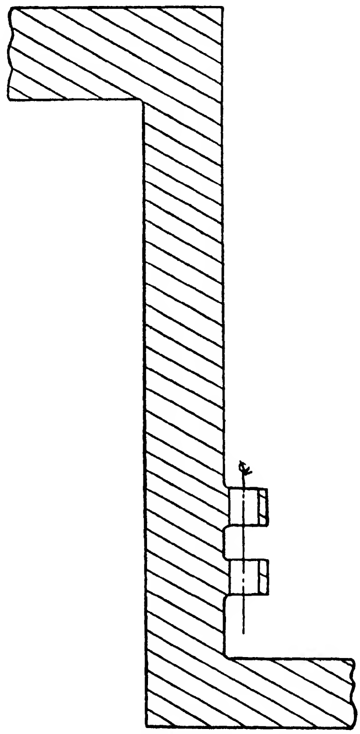


FIG. 9. A Very Poor Casting Design.

The water lines and buttock lines are usually spaced at regular 10-inch intervals, but the station lines may be more erratically spaced so that they will fall on bulkheads or beltframes (which are numbered in accordance with their respective distances from the nose of the airframe).

From the master layout of the airplane as a whole, basic paper layouts of various sections (such as the fuselage, wing, and engine nacelles)

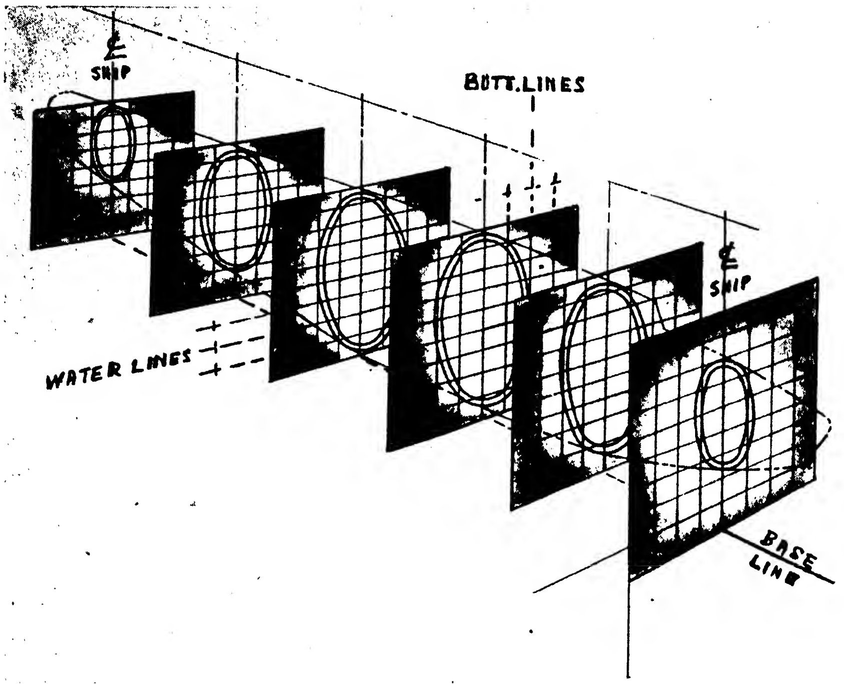


FIG. 10. Buttock and Water Grid Lines in the Third Dimension.

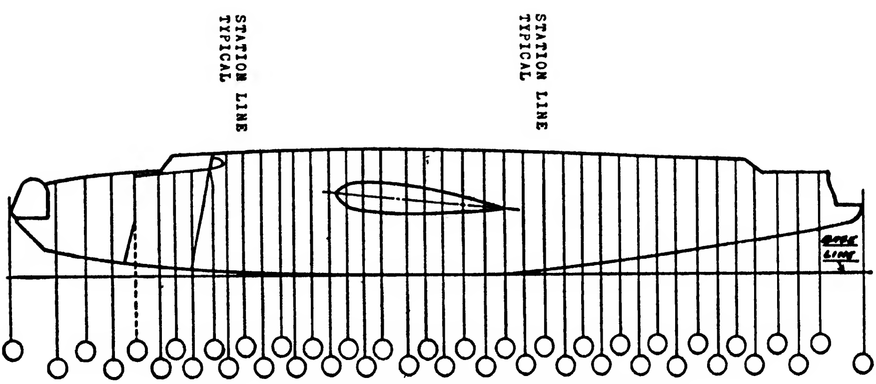


FIG. 11. Station Lines Used in Lofting an Airframe.

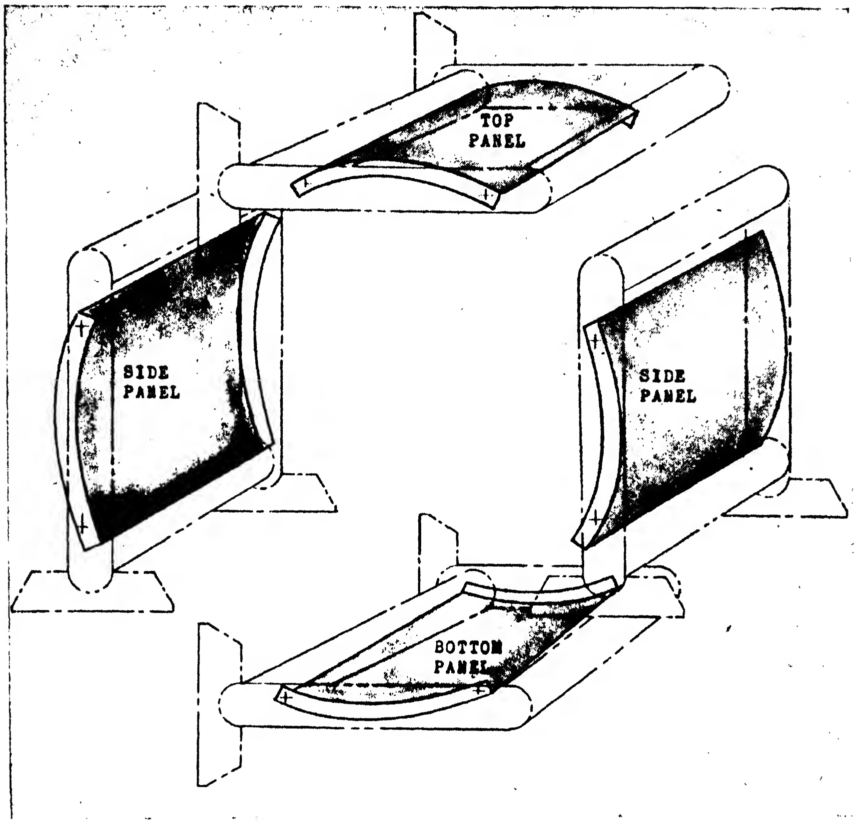


FIG. 12. Parts of a Fuselage Section in Picture-frame Fixtures.

are made. These serve to define the over-all limits of the various sections and to establish the basic and supplementary calculating data, accurate structural locations, and major tooling attachments for each section.

When the basic paper layouts are complete, it becomes practical to break the airframe down into small parts, as explained and illustrated in Chapter 1. It is then possible to design and construct all of the required assembly jigs or fixtures.

Fig. 12 shows with phantom lines how a series of picture-frame fixtures might be used to construct the components that comprise a fuselage section, as determined by a basic breakdown of layout and parts.

CHAPTER 3

DESIGNING JIGS AND FIXTURES

Essential Considerations

TOOL DESIGNING was once considered a guessing game at which any good mechanic could be a success; but modern mass-production methods have changed all that by providing specific requirements which necessitate scientific procedures.

Let us consider the basic requirements for a good jig or fixture:

(1) *It should provide adequate dimensional control.* If the jig or fixture does not enable workmen to fabricate or assemble parts within required tolerances, it will be utterly useless. Certain tolerances must be observed in any form of quantity manufacturing.

(2) *It should facilitate production.* A good jig or fixture will enable workers to get a job done in a specified period of time.

(3) *It should be strong and rugged.* These qualities are especially necessary if the jig or fixture is to be subjected to severe handling, because it would be impractical to have a tool requiring an inspection every hour to insure its dimensional accuracy.

(4) *It should be adaptable.* This is particularly true of an assembly jig or fixture. The primary structure should be large enough to enable tooling men to change the positions of its locating parts so as to conform with slightly varying engineering requirements, without building an entirely new tool; yet it should be small enough to fit into a given area on the factory floor.

(5) *It should be salvageable.* Special production tools are usually made of materials which can be salvaged for further use, once each specified job is complete. For example, metal tools can be readily salvaged by cutting or melting and assembling or casting in different shapes.

(6) *It should be economical.* Good jigs and fixtures are economical both to build and to use.

(7) *It should have a good appearance.* Too often, tool designers

ignore this fact; but it is true that production will suffer when workmen are obliged to work with jigs or fixtures which they dislike.

(8) *It should be readily accessible.* Men never work with maximum efficiency when they are obliged to stoop, bend, stretch, or otherwise contort the members of their bodies. Therefore, it stands to reason that the best jig or fixture will enable the worker to accomplish his job in a normal position.

(9) *It should be simple.* No complicated tool can be loaded, worked, and unloaded with the greatest speed and ease. Accordingly, simplicity should be the keynote of every mass-production tool design.

(10) *It should have every possible safety feature.* The jig or fixture should be as nearly foolproof as possible in order to free its workers from the fear of making mistakes and to prevent injuries due to sharp corners or protruding parts. A dangerous tool is a bad tool.

(11) *It should be easy to manufacture.* Besides being expensive, those tools which require excessive time for fabrication delay the work of constructing other tools vital to production.

(12) *It should be portable.* This is true of any tool that is not to be used in the precise spot were it is fabricated—particularly so if it is to be shipped or otherwise transported for considerable distances.

Fundamentals of Good Tool Design

Generally speaking, tooling experts have found it impractical to copy jig or fixture designs that were previously used with success, because different tolerances, different sizes, and other pertinent factors usually make old designs unsuitable for new jobs. Therefore, the best practice is to start each new design with due consideration for the fundamentals of good engineering.

These fundamentals might be listed as deflection, thermal expansion and contraction, manufacturing tolerances, moments, and location of elements as based on mechanical balance. Accordingly, the tool designer should have some knowledge of physics and mechanics.

Because the structure of an article determines the nature of each tool, the first step in tool designing is to analyze the features of the article to be constructed. This analysis should cover the following items:

(1) Geometrical points and planes which must be located accurately to assure alignment, mating of adjacent parts, and interchangeability of components.

(2) The sequence that must be followed in order to assemble the components efficiently.

(3) The methods by which parts can be handled easily and progressively during assembly.

(4) The selection of certain key parts such as main structural members. (These key parts will ordinarily be found to tie in with smaller parts, which require the least precise locations, and to be directly related to the points and planes which require accurate locations.)

Necessary Drawings

The drawings ordinarily used in constructing jigs or fixtures are orthographic (or straight-line) projections, which may be either full-size or drawn to a suitable scale. However, since they can give only one

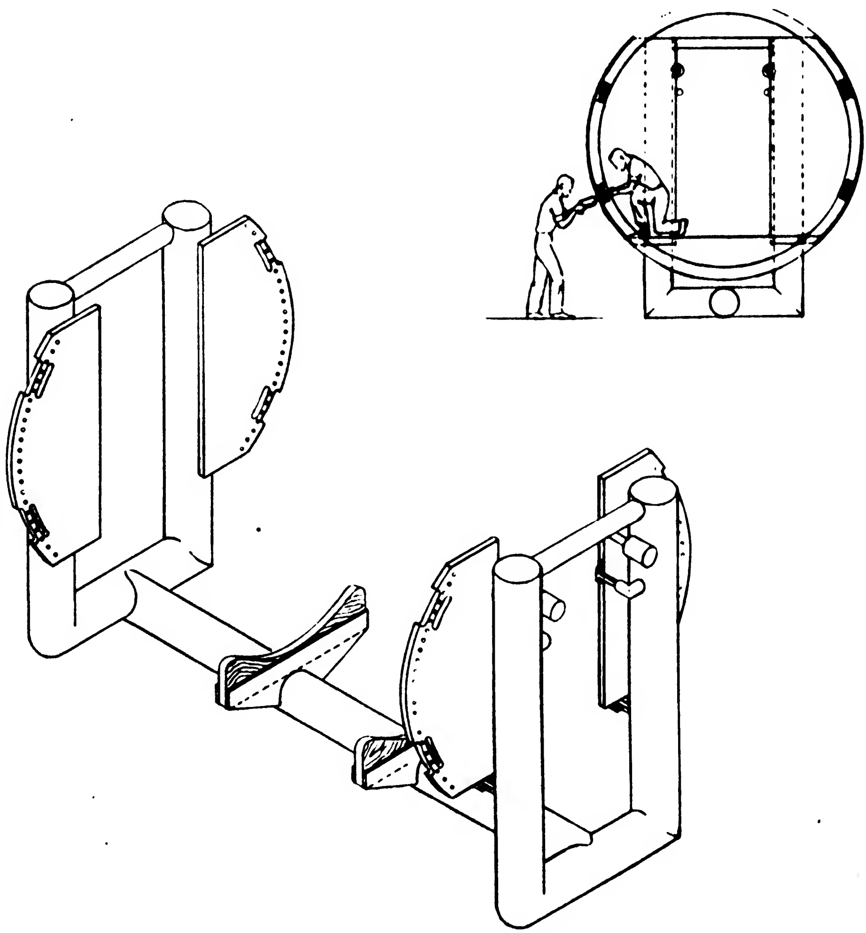


FIG. 13. Arrangement Drawing.

view of the tool at a time, such drawings are sometimes extremely difficult to understand and work from.

Therefore, tool designers have frequently found it expedient to prepare simple pictorial sketches or *arrangement drawings* which will enable men in the fabrication units to visualize the finished three-dimensional layout of the jig or fixture components. A typical arrangement drawing is shown in Fig. 13.

Still another type of drawing which can be advantageously used will be discussed in connection with the master tooling dock in Chapter 6.

Tolerances and Fits

Historical records tell us that near the end of the seventeenth century a gentleman named Wilkinson built a machine which would bore a cylinder with such accuracy that not more than a penny could be placed in the gap between the cylinder wall and its piston. In view of present-day accomplishments, this may seem a bit ridiculous; but the chances are that Wilkinson encountered far greater problems than do modern designers of extremely accurate tools.

Besides producing parts which are dimensionally accurate and interchangeable, we now can intermingle units produced in factories scattered throughout the world—simply by making sure that each of the factories utilizes standard dimensions and gages. In other words, it is mainly a matter of *tolerances and fits.*

The term *fit* is used in mechanical work to denote the proximity with which adjacent members or parts are mated. The five most common classes of fits are:

(1) *Running fit* is used in mating parts whose dimensions must be such that they can be rotated or otherwise moved following assembly.

(2) *Push or press fit* is used in mating parts whose dimensions are such that they can be united with moderate manual or mechanical pressure.

(3) *Drive or driving fit* is used in mating parts whose dimensions are so close they must be driven together with blows.

(4) *Forced fit* is used in mating parts whose dimensions are so close they must be forced together with extreme mechanical pressure.

(5) *Shrinkage fit* is used in mating parts whose dimensions are so close that the female part must be expanded by heat before the male part can be inserted therein. Shrinkage occurs as the female part cools.

Tables showing the dimensional allowances for the principal types of fits will be found in the Appendix. Because the factors which determine allowances vary considerably, these dimensions may sometimes

have to be increased or decreased. For example, the allowances for forced fits usually increase with the diameter to secure greater pressure; but in some shops the allowance is made practically the same for all diameters, because the increased surface area of the larger sizes permits a sufficient increase in pressure.

The term *tolerance* is used to denote the variations permitted in fabricating members or parts of specified dimensions; and, for any given dimension, the tolerance is equal to the maximum and minimum limits. For example, if the maximum limit for the diameter of a shaft is 2 inches and the minimum limit is 1.9 inches, the tolerance is 0.1 inch. Tolerances are established by determining the maximum and minimum clearances required on operating surfaces, and they are necessary in virtually all types of manufacturing because of unavoidable imperfections in workmanship.

The words *tolerance* and *allowance* are often used synonymously; but actually an allowance is a difference in dimensions prescribed in order to secure various classes of fits between different parts.

The two general types of tolerances may be described as follows:

(1) *Unilateral tolerance* refers to the permissible variation from a basic dimension in one direction only. For example, if the basic dimension is 1 inch and the tolerance were expressed as $1-0.005$, or $+0.005$, we would have a unilateral tolerance because the total variation in either case would be in only one direction.

(2) *Bilateral tolerance* refers to the permissible variation from a basic dimension in either of two directions. For example, if the basic dimension is 1 inch and the tolerance is expressed as 1 ± 0.005, we would have a bilateral tolerance because the total variation would extend in two directions.

When unilateral tolerances are required, one of the following three methods should be used to express them:

(1) Specify limiting dimensions only. Examples:

Diameter of hole: 2.250, 2.252
Diameter of shaft: 2.249, 2.247

(2) Specify one limiting size and its tolerance. Examples:

Diameter of hole: 2.250 +0.002, —0.000
Diameter of shaft: 2.249 +0.000, —0.002

(3) Specify the nominal size for both parts with a notation showing the allowance and the tolerance. Examples:

Diameter of hole: $2\frac{1}{4}$ $+0.002$, -0.000
Diameter of shaft: $2\frac{1}{4}$ -0.001, -0.003

Bilateral tolerances are usually specified as such with plus and minus signs of equal amounts. Examples:

$$2\pm0.001, \text{ or } 2 \begin{cases} +0.001 \\ -0.001 \end{cases}$$

According to the practice approved by the Society of Automotive Engineers, a tolerance should show the permissible amount of variation in the direction that is least dangerous. When a variation in either direction is equally dangerous, a bilateral tolerance should be given; and, when a variation in one direction is more dangerous than a variation in another direction, a unilateral tolerance should be given in the least dangerous direction. For nonmating surfaces or atmospheric fits, the tolerances may be bilateral or unilateral, depending entirely upon the nature of the variations that develop in manufacture. On Mating surfaces, with but few exceptions, the tolerances should be unilateral. One exception to the use of unilateral tolerances on mating surfaces occurs when tapers are involved. In such cases either bilateral or unilateral tolerances may be desirable, depending on the circumstances.

Clearances and Human Dimensions

In designing jigs or fixtures for use in connection with machine tools, it is especially necessary to provide clearances for the scraps thrown up in previous operations and in the operation being tooled.

In designing assembly jigs or fixtures, particular attention should be given to the physical dimensions of the persons who must use the tools, in order to eliminate, whenever possible, the necessity for stooping, bending, or stretching. To accomplish this, some tool designers work with diagrams such as those shown in Fig. 14, A and B.

Supporting Structures

The rigidity of an assembly jig or fixture depends largely upon the nature of its supporting structure. For example, a single-beam jig supported at its ends (Fig. 15) will deflect appreciably when a uniform load is applied; and this deflection (represented in an exaggerated condition by dotted lines in the illustration) will be greatest in the center. A similar jig, supported at points some distance from the ends (Fig. 16), will deflect an equal amount in wave form; but the greatest deflection at any point will be far less than at the center of the end-supported beam.

In an investigation of beams of the same sizes it was recently found that the greatest deflection of an end-supported beam was 0.126 inch, whereas a beam supported at points 22.5 per cent in from the ends deflected a maximum of only 0.005 inch. Further, mathematical computations prove that an evenly loaded beam deflects least when supported at two points which are separated by a distance equal to 55.4 per cent of the beam length. However, when the load is not uniform, the supports of a jig or fixture should be spaced so that they will func-

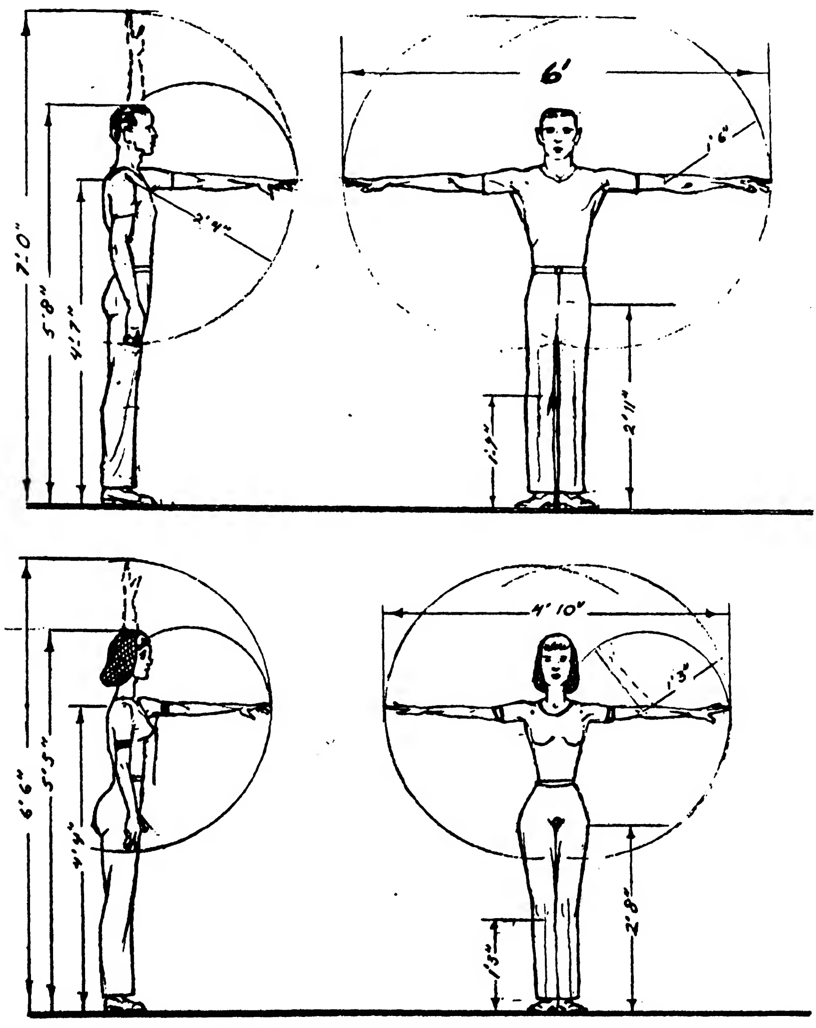


FIG. 14A. Human dimensions Diagram.

tion in a different manner. For instance, on a jig with half the load on one end and less than one quarter on the other, a support should be placed at one tenth the length of the heavily loaded end and at one quarter the length of the other end.

The matter of jig or fixture supports is particularly important in coastal areas, where the positions of factory floors may change every time the tide comes in; or in a new factory, while the ground beneath the floor is settling; or in regions where earthquakes frequently alter the physical characteristics of the ground.

Generally speaking, a jig or fixture with three-point supports is preferable because such suspension will cause the tool to tilt with the floor so that a change in the position of one support will not cause deflection. The chances for deflection in jigs or fixtures with more than three points of support depend upon the number of legs, and increase

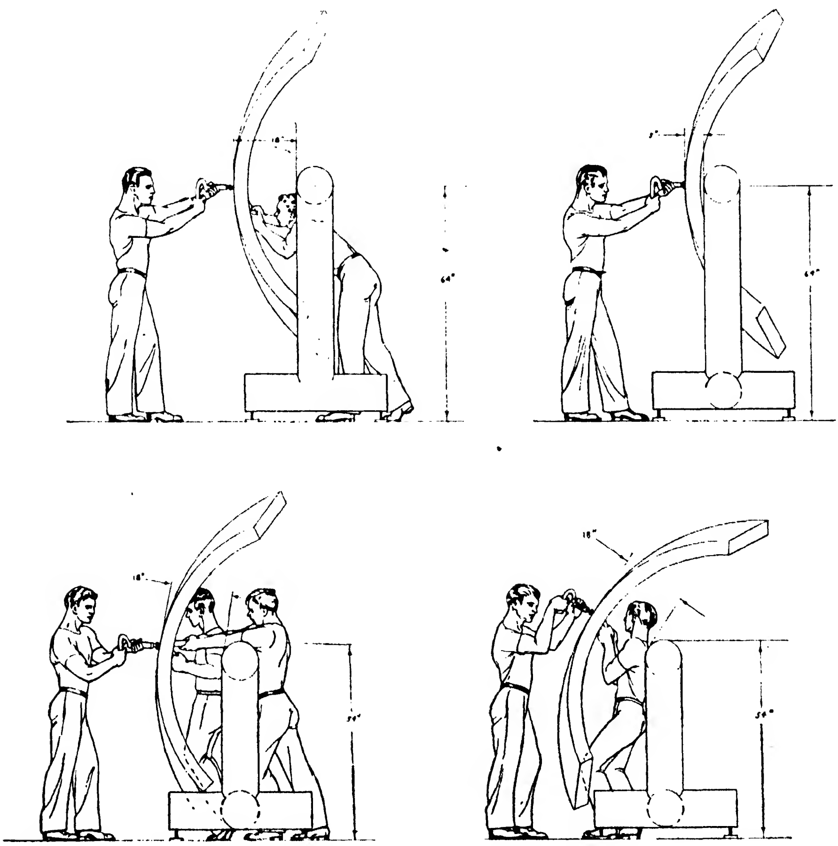


FIG. 14B. Human Dimensions Diagram.

progressively. A complex mating fixture with three-point supports is shown in Fig. 17.

Sometimes four-point supports may seem to be desirable because of the overturning moment to which a jig or fixture may be subjected. In such cases, the benefits of both three-point supports and four-point supports can be attained by utilizing two *safety feet,* such as were described in the specification for picture-frame fixtures in Chapter 2. The safety feet can be mounted on springs, so that they will provide a stabilizing effect rather than a rigid support; or they may have a slight clearance above the floor, so that their only function will be to prevent the overturning of the tool by outside forces. Another way to combine the advantages of three-point and four-point supports is to have two feet at one end of the tool and a light angle crosswise at the

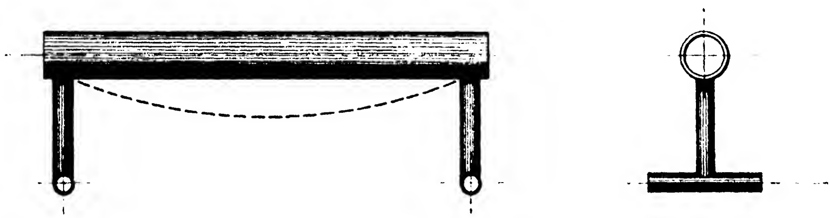


FIG. 15. Single-beam Jig, Supported at Ends.

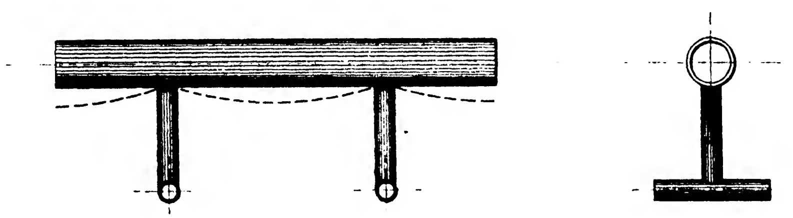


FIG. 16. Single-beam Jig, Supported at Points away from Ends.

other end, so that any change in the floor causes the angle itself to deflect with the floor without altering the structure of the tool.

Another cause for deflection that can be eliminated by proper support is thermal expansion or contraction. On a long jig or fixture whose feet are attached to the floor, deflection will occur as the temperature changes, because the materials in the tool will not expand or contract at the same rate as materials in the floor. To prevent deflection due to thermal expansion or contraction, tool designers usually make arrangements to have the jig or fixture attached to the floor at one end only, allowing the other end to be "floated"—that is, placed on a roller support. Floating one end of the tool permits unrestricted expansion or

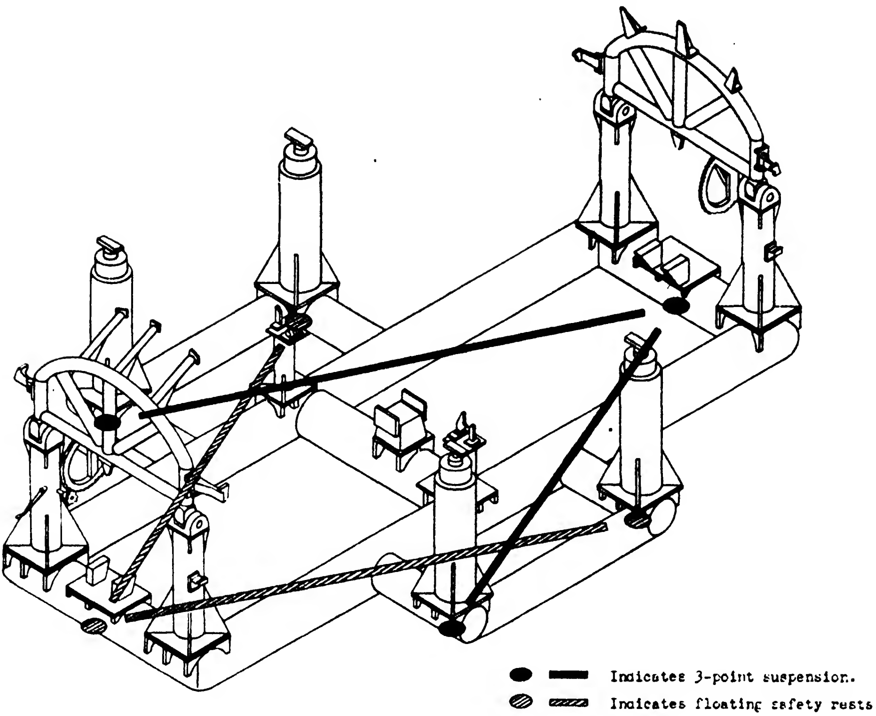


FIG. 17. Mating Fixture.

contraction and introduces no variations in sizes or shapes beyond the increases or decreases in length due to temperature changes.

If the jig or fixture is a master tool, or if its dimensions are such that changes in temperature could alter its usefulness in spite of its supporting structure, the temperature range in which the tool can be used should be plainly marked or stamped on its frame. A thermometer should be placed near-by for reference purposes. Of course, this procedure would not apply in mild climates or in factories where air-conditioning equipment is used.

Locating Points and Sighting Faces

In dealing with jigs or fixtures for use in the machine shop, a tool designer should make sure that all locating points are clearly defined and not such that they are likely to hold swarf swept up from adjacent positions.

Further, when there are *sighting faces,* against which parts of the component being machined must be positioned, the designer should take pains to enable the machine operator to see the faces without

danger to himself. Generally speaking, jigs with sighting faces should be placed on trunnions, for use in connection with machine tools.

Standard Jig or Fixture Details

As previously explained, the answer to virtually every problem presented by mass production is standardization. In tool designing, this answer is most frequently found in the utilization of detail parts of standard jigs or fixtures. Standard jig or fixture elements are desirable

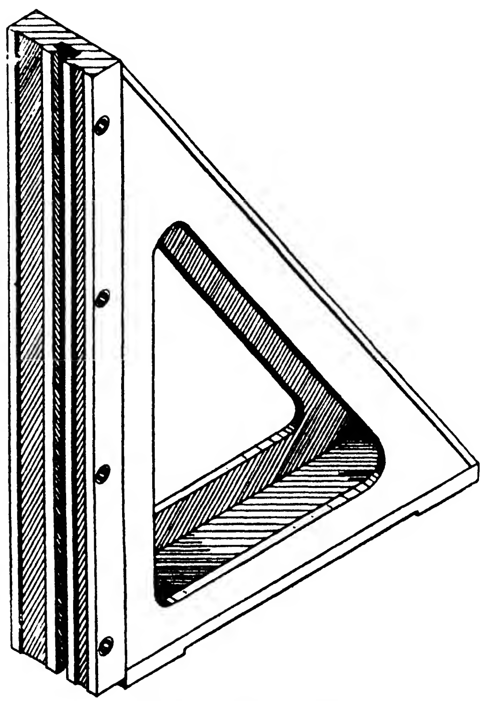


FIG. 18. Angle Block.

because they speed the work of tool designing, help standardize tool-fabrication and -manufacturing methods, eliminate unknown variables, and increase the salvageability of tools. Needless to say, all jig or fixture parts could not possibly be standardized; but it has been found that many of the following can be standardized in almost any factory:

(1) *Blocks.* Three types of blocks are commonly used in connection with jigs or fixtures. They are angle blocks, parallel blocks, and vee or V blocks—specimens of which are respectively indicated in Figs. 18, 19, and 20. In some instances, these blocks may function as

tools by themselves. For example, an angle block can be equipped with drill bushings to serve as a drill jig; parallel blocks can be clamped together to serve as a fixture which will hold work for milling, grinding, or planing; and vee blocks can be capped, clamped, or drilled to serve as either fabrication or assembly tools.

(2) *Bolts.* Some of the bolts commonly used in constructing jigs or fixtures are shown in Fig. 21. Thread and other specifications will be found in the Appendix.

(3) *Brackets.* Three typical brackets, fabricated by welding steel plate for use in connection with assembly jigs or fixtures, are shown in Fig. 22.

(4) *Bushings.* In accordance with specifications of the American Standards Association, as revised in 1941, jig or fixture bushings can be

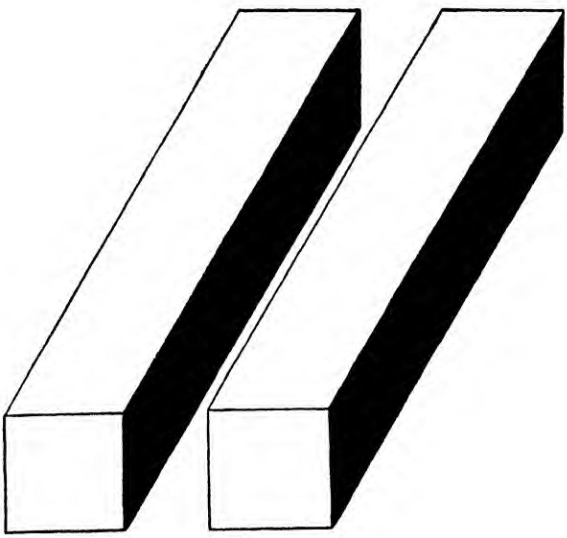


FIG. 19. Parallel Blocks.

classified as the press-fit, renewable, and liner types. Press-fit bushings are installed directly in a tool without the use of a liner, and are used principally on tools for short production runs which do not require replacements. They also are used where the closeness of the center distances of holes will not permit the installation of liners or renewable bushings. Press-fit bushings are made in two types, with and without heads, as indicated in Fig. 23.

Renewable bushings are used in liners, which are directly installed in the jig or fixture. They are employed when it is believed that the

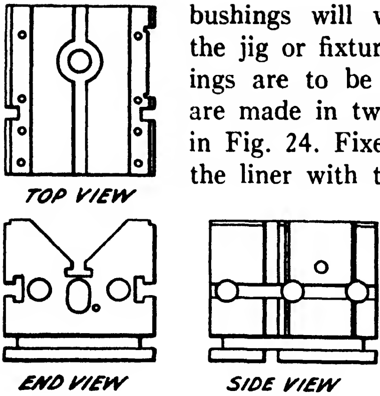


Fig. 20. Vee Blocks.

bushings will wear out or become obsolete before the jig or fixture is discarded or where several bushings are to be interchangeable. Renewable bushings are made in two classes, fixed and slip, as indicated in Fig. 24. Fixed renewable bushings are installed in the liner with the intention of leaving them in place until they are worn out, while slip renewable bushings are interchangeable in a given size of liner. To facilitate removal, the slip renewable bushings usually have knurled heads. They are most frequently used when two or more operations requiring bushings with different diameters are performed in a single tool—such as drilling followed by reaming, tapping, spot-facing, counterboring, or some other secondary operation.

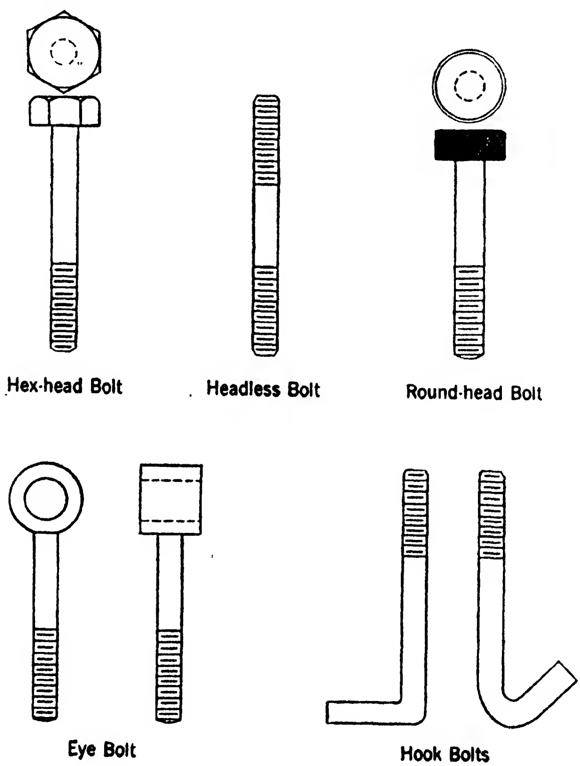


Fig. 21. Bolts.

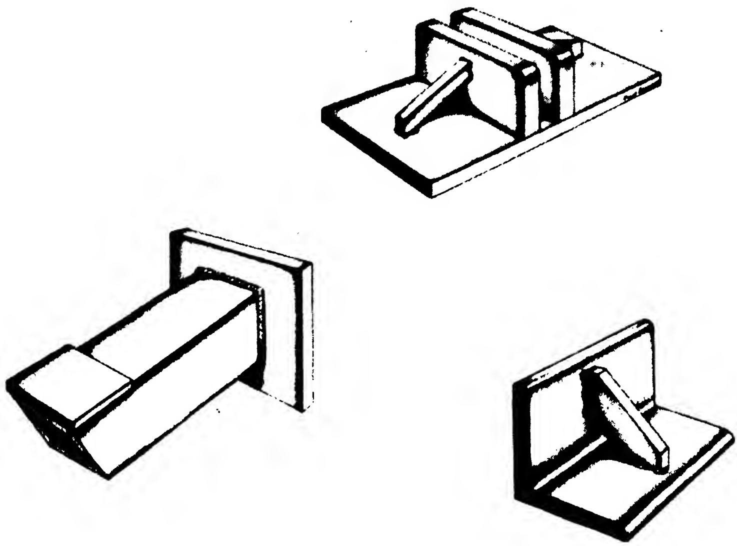


FIG. 22. Brackets.

Liner bushings are provided with and without heads, as indicated in Fig. 25, and may be permanently installed so as to receive the renewable wearing bushings. They are sometimes called *master bushings.*

The standard lengths of jig or fixture bushings are based on uniform jig-plate thicknesses of $\frac{5}{16}$, $\frac{1}{2}$, $\frac{3}{4}$, $1\frac{3}{8}$, and $1\frac{3}{4}$ inches.

(5) *Clamps.* Although numerous types of clamps can be used in connection with jigs or fixtures, most successful manufacturers have found that they can expedite their work by using a comparatively small variety of these devices.

Five simple but useful clamps are shown in Fig. 26. Type A is useful where the work can be slid under the clamp and out again sideways; a spring holds this clamp up while the work is being inserted or removed. Types B and C are extremely valuable on certain jobs because a single turn of the adjustment nut on either is sufficient to allow the clamp to be swung aside. Since these clamps always remain attached to the jig or fixture, they do not necessitate excessive handling. The slotted type-D clamp is adjustable for position lengthways; its most interesting feature is that it can be slid aside or slipped off its bolt in releasing the work. The type-E clamp may be used for a location in connection with any type of jig or fixture.

It should be noted that all of the clamping devices shown in Fig. 26 may be used continuously without their nuts or bolts being removed,

Range of Hole Size[1,2] A		Body Diameter B					Body Length[4] C			Width of Chamfer[5] D	Head Diameter[6] F	Head Height G
		Unfinished[3]			Finished							
From	Up to and Including	Nominal	Max	Min	Max	Min	Short	Medium	Long		Max	Max
0.0156	0.0625	5/32	0.166	0.161	0.1578	0.1575	5/16		1/2	1/32	1/4	3/32
0.0630	0.0995	13/64	0.213	0.208	0.2046	0.2043	5/16		1/2	1/32	5/16	3/32
0.1024	0.1378	1/4	0.260	0.255	0.2516	0.2513	5/16		1/2	1/32	3/8	3/32
0.1406	0.1875	5/16	0.327	0.322	0.3141	0.3138	5/16	1/2	3/4	1/32	7/16	1/8
0.1910	0.2500	13/32	0.421	0.416	0.4078	0.4075	5/16	1/2	3/4	1/16	17/32	5/32
0.2520	0.3125	1/2	0.520	0.515	0.5017	0.5014	5/16	1/2	3/4	5/64	5/8	7/32
0.3160	0.4219	5/8	0.645	0.640	0.6267	0.6264	1/2	3/4	1	3/32	13/16	7/32
0 4375	0.5000	3/4	0.770	0.765	0.7518	0.7515	1/2	3/4	1	7/64	15/16	7/32
0.5156	0 6250	7/8	0.895	0.890	0.8768	0.8765	3/4	1	1 3/8	7/64	1 1/8	1/4
0.6406	0.7500	1	1.020	1.015	1.0018	1.0015	3/4	1	1 3/8	7/64	1 1/4	5/16
0.7656	1.0000	1 3/8	1.395	1.390	1.3772	1.3768	3/4	1	1 3/8	9/64	1 5/8	3/8
1.0156	1.3750	1 3/4	1.770	1.765	1.7523	1.7519	1	1 3/8	1 3/4	9/64	2	3/8
1.3906	1.7500	2 1/4	2.270	2.265	2.2525	2 2521	1	1 3/8	1 3/4	7/32	2 1/2	3/8

All dimensions given in inches.

Tolerance on fractional dimensions where not otherwise specified shall be ±0.010 inch.

[1] Hole sizes are in accordance with the American Standard for Twist Drill Sizes (ASA B5.12–1940).

[2] The maximum and minimum values of the hole size, A, shall be as follows:

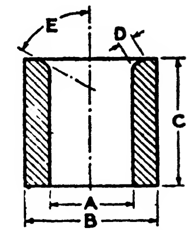
Nominal Size of Hole	Maximum	Minimum
Above 0.0000 to 1/4 in. incl.	Nominal +0.0004 in.	Nominal +0.0001 in.
Above 1/4 to 3/4 in. incl.	Nominal +0.0005 in.	Nominal +0.0001 in.
Above 3/4 to 1 1/2 in. incl.	Nominal +0.0006 in.	Nominal +0.0002 in.
Above 1 1/2	Nominal +0.0007 in.	Nominal +0.0003 in.

[3] The body diameter, B, for unfinished bushings is larger than the nominal diameter in order to provide grinding stock for fitting to jig plate holes. The grinding allowance is 0.005 to 0.010 in. for sizes 5/32, 13/64, and 1/4 in., 0.010 to 0.015 in. for sizes 5/16 and 13/32 in., and 0.015 to 0.020 in. for sizes 1/2 in. and up.

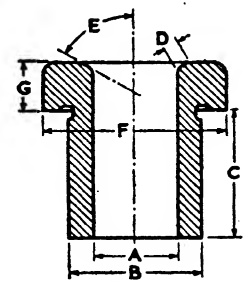
[4] The length, C, is the overall length for the headless type and the length underhead for the head type.

[5] The angle of chamfer, E, shall be 59 deg ± 1 deg and a slight radius shall be provided at the intersection of this chamfer with the hole, A.

[6] The head design shall be in accordance with the manufacturer's practice.



PRESS FIT, HEADLESS WEARING BUSHING



PRESS FIT, HEAD TYPE WEARING BUSHING

Fig. 23. Press-fit Bushings.

Range of Hole Size[1,2] A		Body Diameter B			Width of Chamfer[3] D	Head Diameter[4] F
From	Up to and Including	Nominal	Max	Min		Max
0.0000	0.1562	5/16	0.3125	0.3123	1/32	5/8
0.1610	0.3125	1/2	0.5000	0.4998	5/64	15/16
0.3160	0.5000	3/4	0.7500	0.7498	7/64	1 1/4
0.5156	0.7500	1	1.0000	0.9998	7/64	1 5/8
0.7656	1.0000	1 3/8	1.3750	1.3747	9/64	2
1.0156	1.3750	1 3/4	1.7500	1.7497	9/64	2 1/2
1.3906	1.7500	2 1/4	2.2500	2.2496	7/32	3

All dimensions given in inches.

Tolerance on fractional dimensions where not otherwise specified shall be ±0.010. inch.

[1] Hole sizes are in accordance with the American Standard for Twist Drill Sizes (ASA B5.12–1940).

[2] The maximum and minimum values of hole size, A, shall be as follows:

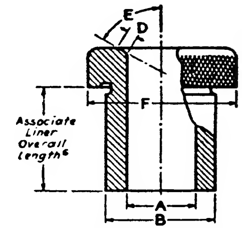
Nominal Size of Hole	Maximum	Minimum
Above 0.0000 to 1/4 in. incl.	Nominal +0.0004 in.	Nominal +0.0001 in.
Above 1/4 to 3/4 in. incl.	Nominal +0.0005 in.	Nominal +0.0001 in.
Above 3/4 to 1 1/2 in. incl.	Nominal +0.0006 in.	Nominal +0.0002 in.
Above 1 1/2	Nominal +0.0007 in.	Nominal +0.0003 in.

[3] The angle of chamfer, E, shall be 59 deg ± 1 deg and a slight radius shall be provided at the intersection of this chamfer with the hole, A.

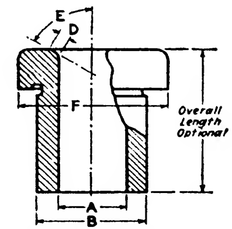
[4] The head design shall be in accordance with the manufacturer's practice.

[5] Head of slip type is usually knurled.

[6] When renewable wearing bushings are used with liner bushings of the head type, the length under head should be increased over the jig plate thickness by the thickness of the liner bushing head.

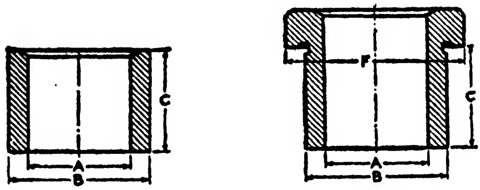


SLIP TYPE, RENEWABLE WEARING BUSHING



FIXED TYPE, RENEWABLE WEARING BUSHING

Fig. 24. Renewable Bushings.



Range of Hole Size in Renewable Wearing Bushings*		Inside Diameter *A* of Liner Bushing			Body Diameter *B* Unfinished		
From	To and Incl.	Nom.	Max.	Min.	Nom.	Max.	Min.
0.0000	0.1562	5/16	0.3129	0.3126	1/2	0.520	0.515
0.1610	0.3125	1/2	0.5005	0.5002	3/4	0.770	0.765
0.3160	0.5000	3/4	0.7506	0.7503	1	1.020	1.015
0.5156	0.7500	1	1.0007	1.0004	1 3/8	1.395	1.390
0.7656	1.0000	1 3/8	1.3760	1.3756	1 3/4	1.770	1.765
1.0156	1.3750	1 3/4	1.7512	1.7508	2 1/4	2.270	2.265
1.3906	1.7500	2 1/4	2.2515	2.2510	2 3/4	2.770	2.765

Range of Hole Size in Renewable Wearing Bushings*		Body Diameter *B* Finished		Jig Plate Thickness *C*			Head Diam. *F*
From	To and Incl.	Max.	Min.	Short	Medium	Long	Max.
0.0000	0.1562	0.5017	0.5014	5/16	1/2	3/4	5/8
0.1610	0.3125	0.7518	0.7515	5/16	1/2	3/4	15/16
0.3160	0.5000	1.0018	1.0015	1/2	3/4	1	1 1/4
0.5156	0.7500	1.3772	1.3768	3/4	1	1 3/8	1 5/8
0.7656	1.0000	1.7523	1.7519	3/4	1	1 3/8	2
1.0156	1.3750	2.2525	2.2521	1	1 3/8	1 3/4	2 1/2
1.3906	1.7500	2.7526	2.7522	1	1 3/8	1 3/4	3

* Minimum body diameter, *B* for unfinished bushings, is 0.015 to 0.020 inch larger than nominal diameter to provide grinding stock for fitting to jig plate holes. Tolerance on fractional dimensions where not otherwise specified shall be ±0.010 inch. The head design shall be in accordance with the manufacturer's practice. The length, *C*, is the over-all length for the headless type and the length under head for the head type.

FIG. 25. Liner Bushings.

loosening being normally sufficient for the insertion or removal of the work.

(6) *Equalizing devices.* These are usually the same as vise jaws, except that each is a combination of movable jaws while the ordinary vise comprises one fixed jaw and one movable jaw. When used in connection with machine jigs or fixtures, equalizing devices serve to make allowances for slight variations in unfinished work and holding various pieces of work in the proper positions for machining. Some typical equalizing devices are shown in Fig. 27.

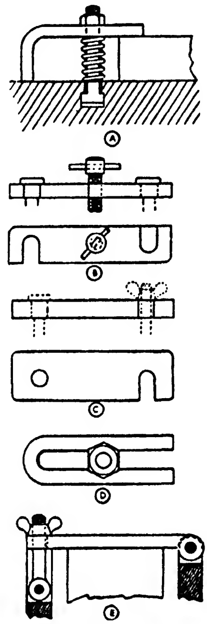


FIG. 26. Clamps.

(7) *Feet.* Each kind of jig or fixture usually requires a specified type of feet or supporting members. In most factories these units can be standardized without difficulty. For example, Fig. 28 shows specifications for feet which can be used when it is necessary to attach such supports to the jig or fixture body by means of screws.

(8) *Handles or hooks.* If jigs or fixtures or parts thereof must be moved or lifted, they should be provided with handles or hooks. One of the more interesting of these is the handle shown in Fig. 29. This device is used in removing slip bushings.

(9) *Index mechanisms.* Index mechanisms make it possible to use a single jig or fixture for several operations. Sometimes indexing is accomplished by rotating the jig or fixture; at other times, by moving the tool in a straight line successively under two or more spindles. Some typical index mechanisms are shown in Fig. 30.

(10) *Inserts.* Since a clamp should never be used to take the pressure of a cutting tool, it is sometimes necessary for jigs or fixtures to have inserts at fixed location points to eliminate the necessity of holding the work on the bases of the tools. Inserts get their name by virtue of the fact that their bases are inserted in holes at the required location points. They may be made from numerous materials—metals, leather, or fiber.

Three typical inserts are shown in Fig. 31. Type A is especially suitable for taking the thrust of a drill for a drill jig, since the hole in its center is of a clearance size which will enable the drill to pass on through. Type B could be used to locate or support any work in either a jig or a fixture. Since it is adjustable, it can be easily set to the required position. Type C was designed to locate or support work with irregular or curved surfaces. When possible, the locating point of an

insert should be small so that there will be less danger of dirt lodging, thus causing inaccuracies.

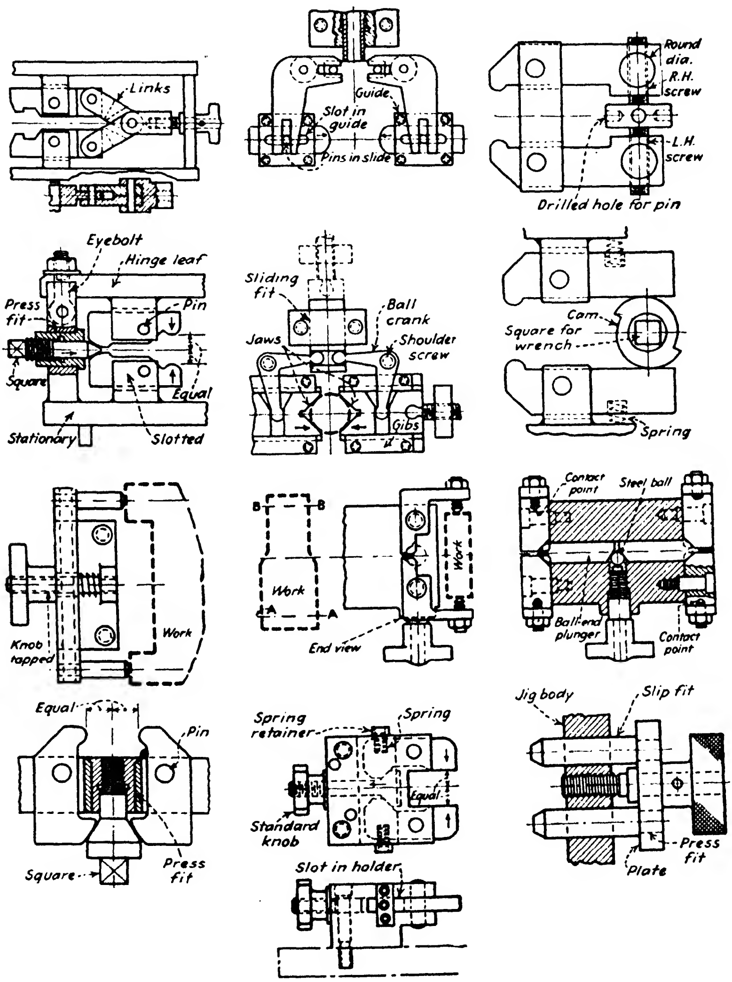
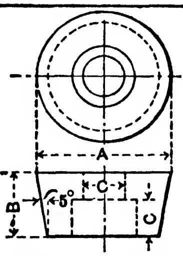


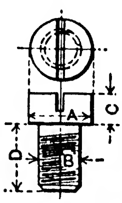
FIG. 27. Equalizing Devices.

Standard Jig Feet



A	B	C	A	B	C
3/8	3/16	1/8	1 3/16	1 3/32	7/32
7/16	7/32	9/64	3/4	3/8	1/4
1/2	1/4	5/32	7/8	7/16	9/32
9/16	9/32	11/64	1	1/2	5/16
5/8	5/16	3/16	....	....	....

Screws for Jig Feet



A	B	C	D	A	B	C	D
0.160	1/8	0.110	9/32	0.299	7/32	0.192	7/16
0.191	9/64	0.123	5/16	0.343	1/4	0.219	15/32
0.213	5/32	0.137	11/32	0.386	9/32	0.246	1/2
0.233	11/64	0.150	3/8	0.426	5/16	0.273	17/32
0.256	3/16	0.164	13/32	.....	....	.....	....

Fig. 28. Feet.

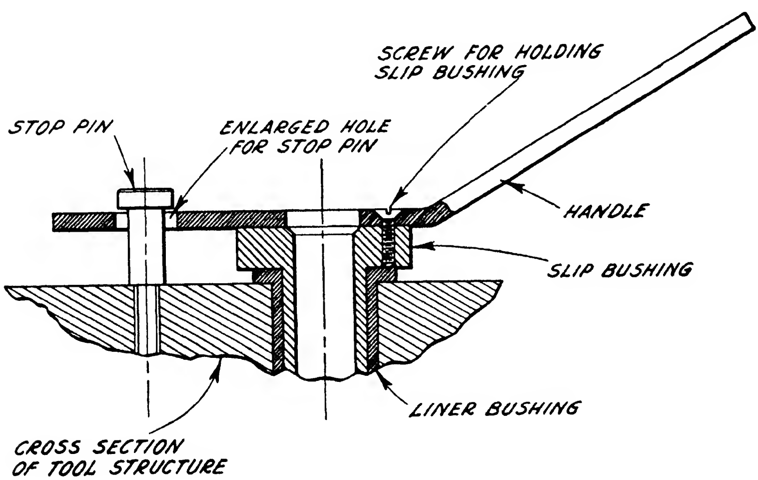


Fig. 29. Handle.

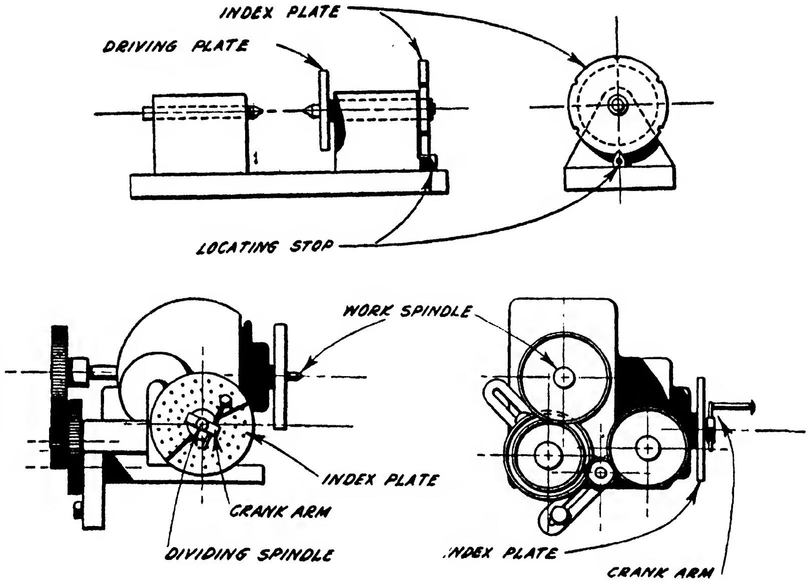


FIG. 30. Index Mechanisms.

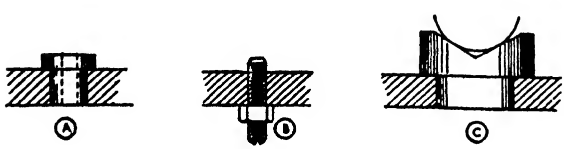


FIG. 31. Inserts.

(11) *Jacks.* It is not always possible to clamp the work directly either to the base or to one of the walls of a jig or fixture, because the component may not be machined at those points where it is most convenient to effect the clamping. Jacks may then be used as work supports. Some typical jacks are shown in Fig. 32.

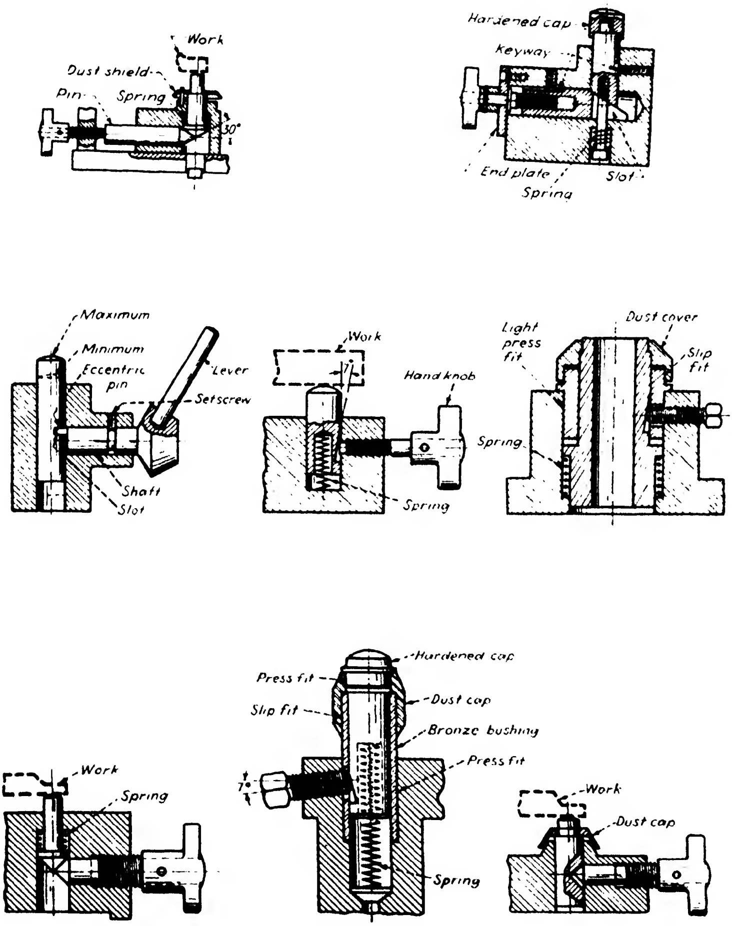
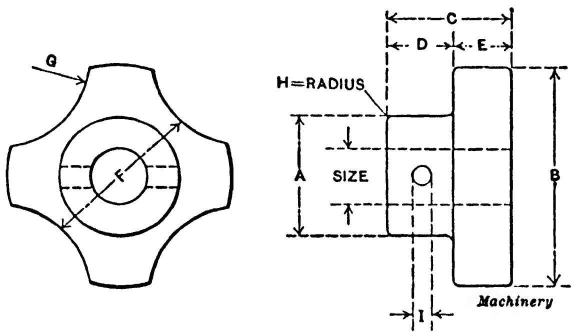
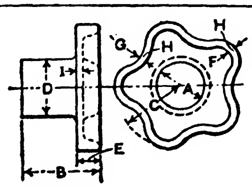


Fig. 32. Jacks.

(12) *Knobs.* Knobs may be used on screw heads, if it is necessary to tighten the screws without using a wrench. Some typical knob specifications are shown in Fig. 33. As a rule, knobs are used when the screw head is less than an inch in height; otherwise, a pin may be inserted in a hole through the screw head so that two hands can be used in tightening or loosening the screw.



Size	5/16	3/8	1/2	9/16	5/8	3/4
A	11/16	7/8	1 1/16	1 3/16	1 1/4	1 1/2
B	1 1/4	1 5/8	2 1/8	2 3/8	2 3/4	3
C	11/16	7/8	1	1 1/16	1 1/4	1 1/4
D	3/8	1/2	5/8	5/8	3/4	3/4
E	5/16	3/8	3/8	7/16	1/2	1/2
F	7/8	1	1 3/16	1 1/2	1 1/2	1 3/4
G	1/2	9/16	5/8	3/4	7/8	1
H	1/16	3/32	3/32	1/8	1/8	1/8
I	3/32	3/32	1/8	3/16	3/16	3/16



A	B	C	D	E	F	G	H	I
3/4	1 3/4	1	1	3/8	3/16	5/16	1/8	1/8
1	1 7/8	1 1/4	1 1/8	7/16	5/16	7/16	1/8	1/8
1 1/8	2	1 1/2	1 3/8	1/2	3/8	9/16	3/16	3/16
1 1/2	2 1/8	2	1 5/8	9/16	1/2	11/16	3/16	3/16
1 5/8	2 1/4	2 1/2	1 3/4	5/8	7/8	7/8	3/16	1/4

FIG. 33. Knobs. *Upper:* Cast-iron knob dimensions. *Lower:* Star handwheel dimensions.

(13) *Leafs.* In connection with clamping and indexing mechanisms, it is frequently necessary to utilize devices known as *leafs*. Some typical leafs are shown in Fig. 34. These devices get their name by virtue of their leaflike appearance. Their function is simply to swing to and fro.

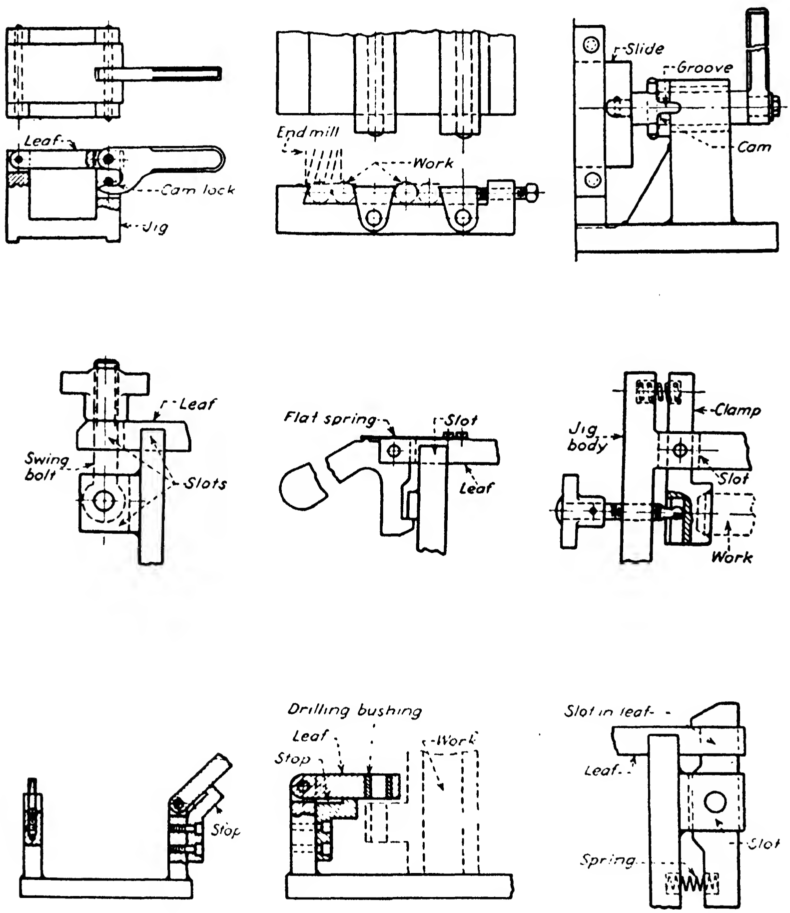


Fig. 34. Leafs.

(14) *Locks.* No matter how indexing is accomplished in a jig or fixture, it is necessary to provide means for accurate work locations at each station. Accordingly, we have locking mechanisms such as those shown in Fig. 35. In all these examples, the plunger and its bushings are hardened to reduce wear to a minimum. While the plunger should slide easily into the indexing hole, the fit should be snug if accuracy is desired.

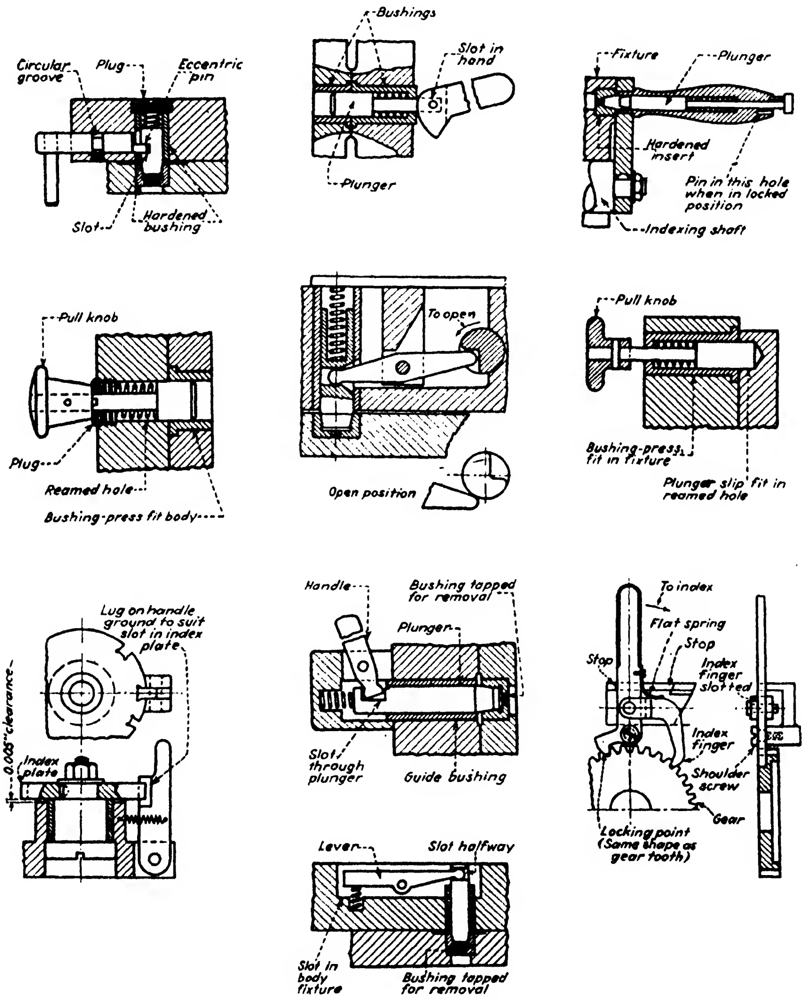


Fig. 35. Locks.

(15) *Nuts.* Some of the nuts commonly used in connection with jigs or fixtures are shown in Fig. 36. Thread and other specifications for them will be found in the Appendix.

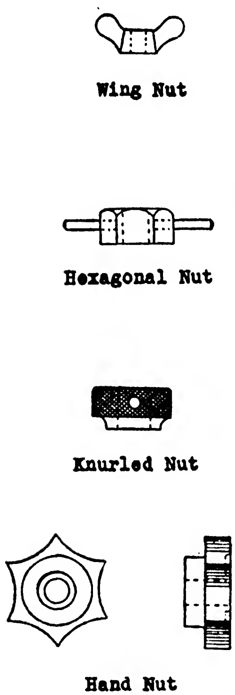


FIG. 36. Nuts.

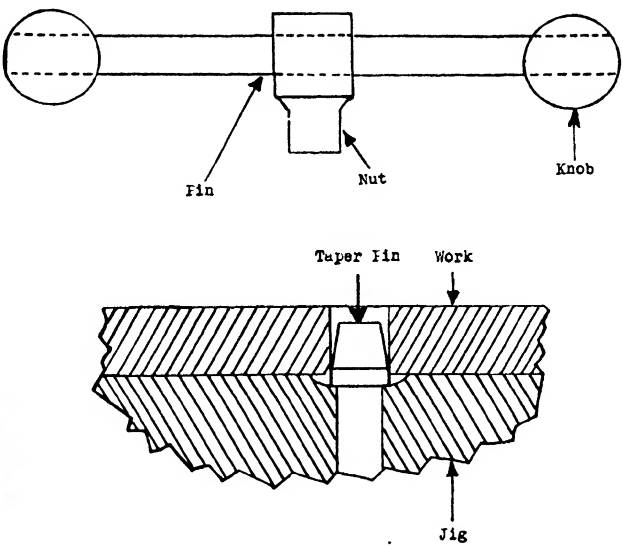


FIG. 37. Pins.

(16) *Pins.* Several types of pins can be used in jig or fixture construction, and their functions generally are to hold, support, or locate parts of the work or parts of the tool itself. Some typical applications of pins are indicated in Fig. 37.

(17) *Screws.* Some of the screws commonly used in connection with jigs or fixtures are shown in Fig. 38. Thread and other specifications for these screws will be found in the Appendix.

(18) *Vise jaws.* These holding or clamping units are especially useful in connection with milling jigs or fixtures. They are almost the same as equalizing devices, which have already been discussed. Fig. 39 shows a variety of vise jaws, each of which was designed for use with machine tools.

(19) *Washers.* As a rule, any ordinary washer can be used in constructing jigs or fixtures. However, in the assembly of clamping devices, it has been found that spherical washers are most advantageous. Fig. 40 shows how spherical washers may be used and gives an appropriate set of specifications. The two parts of a spherical washer are normally made from S.A.E. 1020 steel which has been carburized, hardened, and ground after machining to shape. It has been found desirable, though not essential, to lap the mating surfaces of the two sections together for a smooth fit. Spherical washers are used under the clamping nuts or knobs of jig or fixture clamps in order to attain closer fits than would be possible with pairs of ordinary washers.

FIG. 38. Screws.

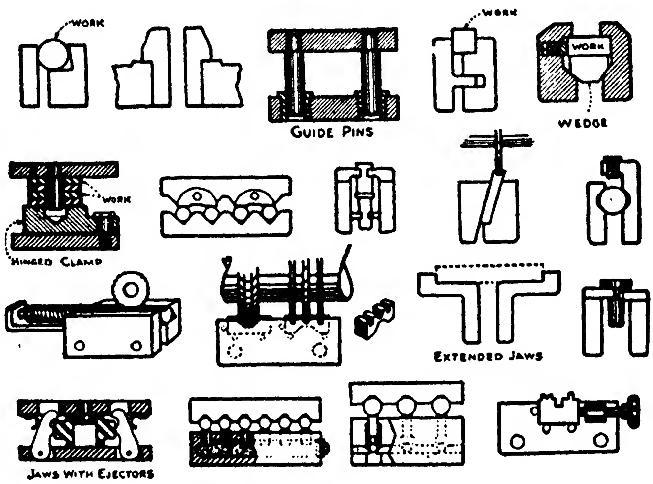
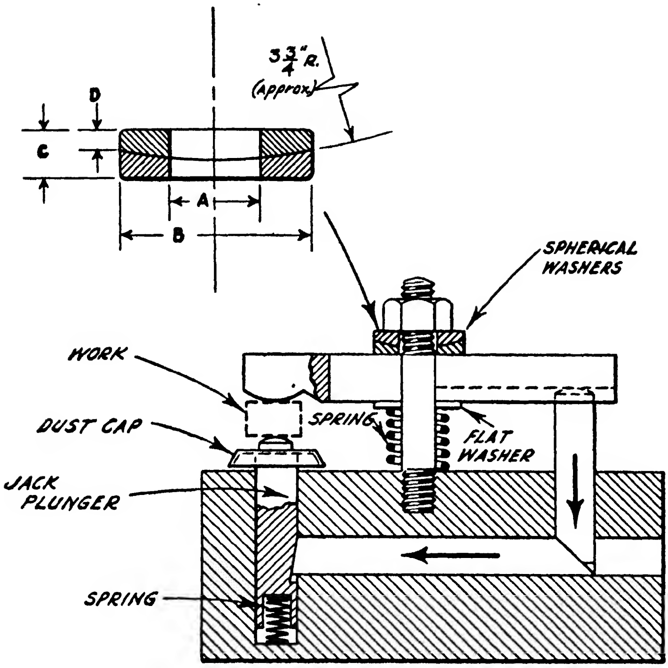


FIG. 39. Vise Jaws.



Size of Screw	A—Diameter of hole	B—Outside diameter	C—Thickness of assembly	D—Thickness of washer
1/4	9/32	5/8	9/32	9/64
5/16	11/32	3/4	9/32	9/64
3/8	13/32	7/8	5/16	5/32
7/16	15/32	1	5/16	5/32
1/2	17/32	1 1/8	3/8	3/16
9/16	19/32	1 3/16	3/8	3/16
5/8	21/32	1 1/4	3/8	3/16
3/4	25/32	1 1/2	3/8	3/16
7/8	15/16	1 3/4	1/2	1/4
1	1 1/16	2	1/2	1/4
1 1/8	1 3/16	2 1/4	1/2	1/4
1 1/4	1 5/16	2 1/2	1/2	1/4
1 1/2	1 9/16	2 3/4	1/2	1/4

FIG. 40. Spherical Washers.

Foolproofing

A jig or fixture is considered *foolproof* when its structure is such that an operator cannot insert either a work-piece or a tool into any position other than the right one. Foolproofing can usually be accomplished by locating pins or abutments so that they will clear or foul the component in accordance with whether the component is in the correct or incorrect position, and by varying the sizes of pilot bushings so that cutting tools cannot be inserted in the wrong holes.

When the symmetry of a component makes it impractical to utilize the pin or abutment method of foolproofing, tool designers frequently find it possible to insure the correct alignment of parts by varying the sizes of the tooling holes, which are sometimes used to locate components in jigs or fixtures. A variation of this method is to add a small locating hole to the component, so that the hole will slip over a pin or abutment on the jig or fixture when the component is correctly positioned.

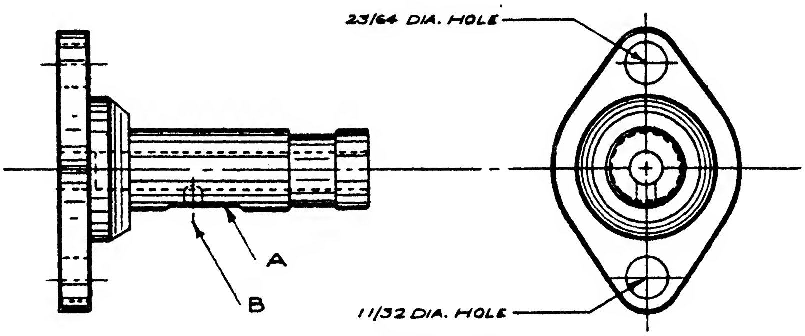


FIG. 41. Foolproofing.

An example of foolproofing is shown in Fig. 41. Here a flat had to be milled on the component at *A*, so that it would have proper relationship to hole *B*. If the fixture for holding the component had not been foolproofed, it would have been easy for an operator to mill a flat on the component at a point opposite hole *B*. The foolproofing was accomplished simply by varying the sizes of the holes in the base of the component and the pins over which these holes were to be fitted in the fixture.

Tool Production Chart

Although no two factories have identical procedures for tool design and fabrication, the reader would do well to study at this point the Tool Production Chart facing page 200.

This chart represents one of the most efficient tooling programs ever developed for the construction of airframes. While the chart may appear to be a bit complicated at first glance, its over-all simplicity is amazing in view of the fact that it outlines specific methods of tooling up for the production of more than a million different aircraft parts and assemblies. Some manufacturers could use a larger chart than this just to outline their methods of creating tools for the production of lawn mowers.

Probably the most remarkable feature of the chart is that it does not necessitate specific tool designs for a large number of jigs and fixtures. (For example, it calls for the Automatic Riveting Fixtures, whose fabrication process will be completely described in Chapter 10.) It has been estimated that this feature alone reduces the manufacturer's tooling costs by about 25 per cent.

When they are required, individual tool designs are created in the form of rough drawings from reproductions of basic engineering drawings by the factory's tool planners. When these roughs have been approved by the factory's tool engineers, they are made into finished drawings and conveyed to the groups whose duties involve the fabrication of tools.

The basis of the program is in every case a master layout which is an extremely accurate reproduction of a full-scale engineering drawing. This layout is retained in a "master tooling loft," so that essential and accurate engineering information can be made constantly available to all tooling personnel.

Tool planners order templates and tools in accordance with a system of easy-to-remember letter symbols; and because the equipment necessary for each job is directly specified by the Tool Production Chart, the chances for confusion due to improperly worded orders are greatly minimized.

All this reduces the number of tooling problems that must be coped with, and enables the tool engineers to devote more time to the extremely important job of modifying preliminary engineering designs so that each new airplane can be constructed with maximum speed and economy. However, it does not mean that the tooling program itself is exempt from change. Alterations are constantly being made in all phases of the procedure. If at any time it is found that certain units will not have the desired quality when produced by standardized methods, then other methods are either adopted or developed immediately.

After reading Chapter 6, which describes the "Master Tooling Dock," the reader should again refer to the Tool Production Chart and note the tooling dock (TODC) notations. He should then observe that the

chart calls for the use of both the dock and conventional masters. This was necessary because the manufacturer's tooling dock facilities were not extensive enough for the fabrication of all necessary assembly tools at the time the chart was originated.

CHAPTER 4

TYPES OF JIGS AND FIXTURES

Nomenclature Difficulties

IT IS DIFFICULT to name all the specific types of jigs or fixtures, because these tools may be employed in connection with a wide variety of jobs. As a matter of fact, many industries utilize jigs or fixtures and call them by other names—for example, the composing stick used by printers is a fixture.

This chapter will be confined to descriptions of those tools most generally known as jigs or fixtures. Some of the more unusual types will be discussed in the last chapter.

Adjustable Fixtures

Adjustable fixtures are used in machining components of the same general types, but with varied dimensions, in turret lathes and in vertical boring mills. They save the cost of having a different tool for each set of dimensions, but they are not often used for mass production because their speed and accuracy depends greatly on the skill of the operator.

Fig. 42 shows one of the few adjustable fixtures that have proved themselves to be of value in mass production. The merit of this tool is that it can be set up in a lathe so as to machine five surfaces simultaneously.

Assembly Jigs or Fixtures

As the name implies, assembly jigs or fixtures serve to hold parts in the process of assembling the components of a structure. For this reason, they are sometimes called *holding* or *mating* jigs or fixtures. Specific types of these tools are:

(1) *Bench assembly jigs or fixtures.* These jigs or fixtures are comparatively small tools which can be attached to or used in connec-

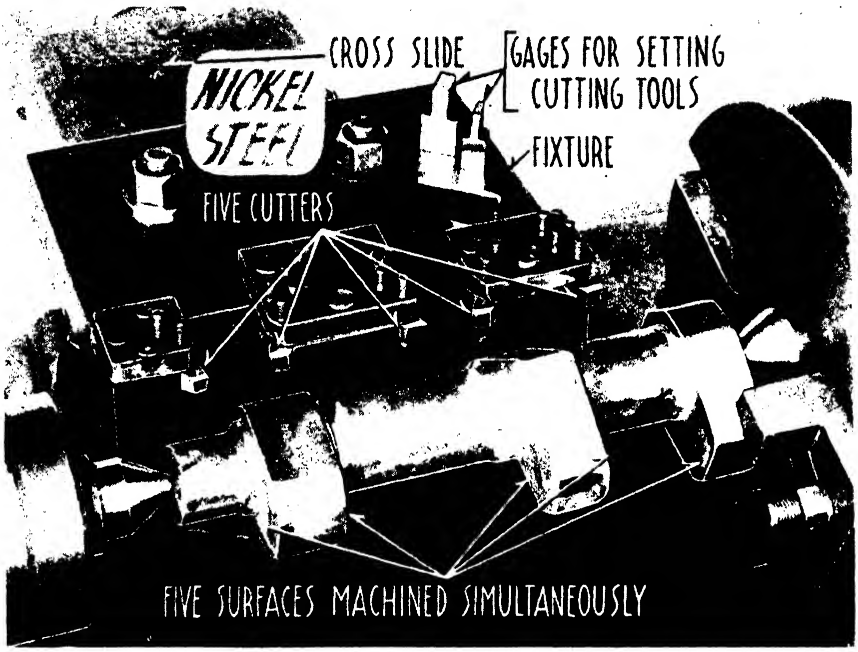


FIG. 42. Adjustable Fixture.

tion with a work bench. A typical bench assembly fixture is shown in Fig. 43. This tool is used in assembling a complex system of tubing. Similar units can be used to assemble electrical wires, cables, or innumerable other small parts in predetermined sequences.

(2) *Detail assembly jigs or fixtures.* Tools of this type are used only in connection with single operations—for example, the welding of two components. Fig. 44 shows a conventional detail assembly tool. The purpose of this fixture is to hold an electrical plug during the process of soldering.

(3) *Picture-frame jigs or fixtures.* These tools are so named because each surrounds its assembly as a frame surrounds a picture. A typical picture-frame fixture was illustrated and described in Chapter 2. Tools of this type are generally used to assemble sheet-metal parts whose layouts are essentially two-dimensional. They may be mounted on a moving assembly line or attached to the factory floor.

(4) *Single-beam jigs or fixtures.* When long and narrow assemblies are to be made, single-beam jigs or fixtures are ordinarily employed. As indicated in Fig. 45, a single-beam jig comprises a single-beam member with locators or holding devices which extend away from the beam, and a suitable supporting structure. If the beam can be so turned as to

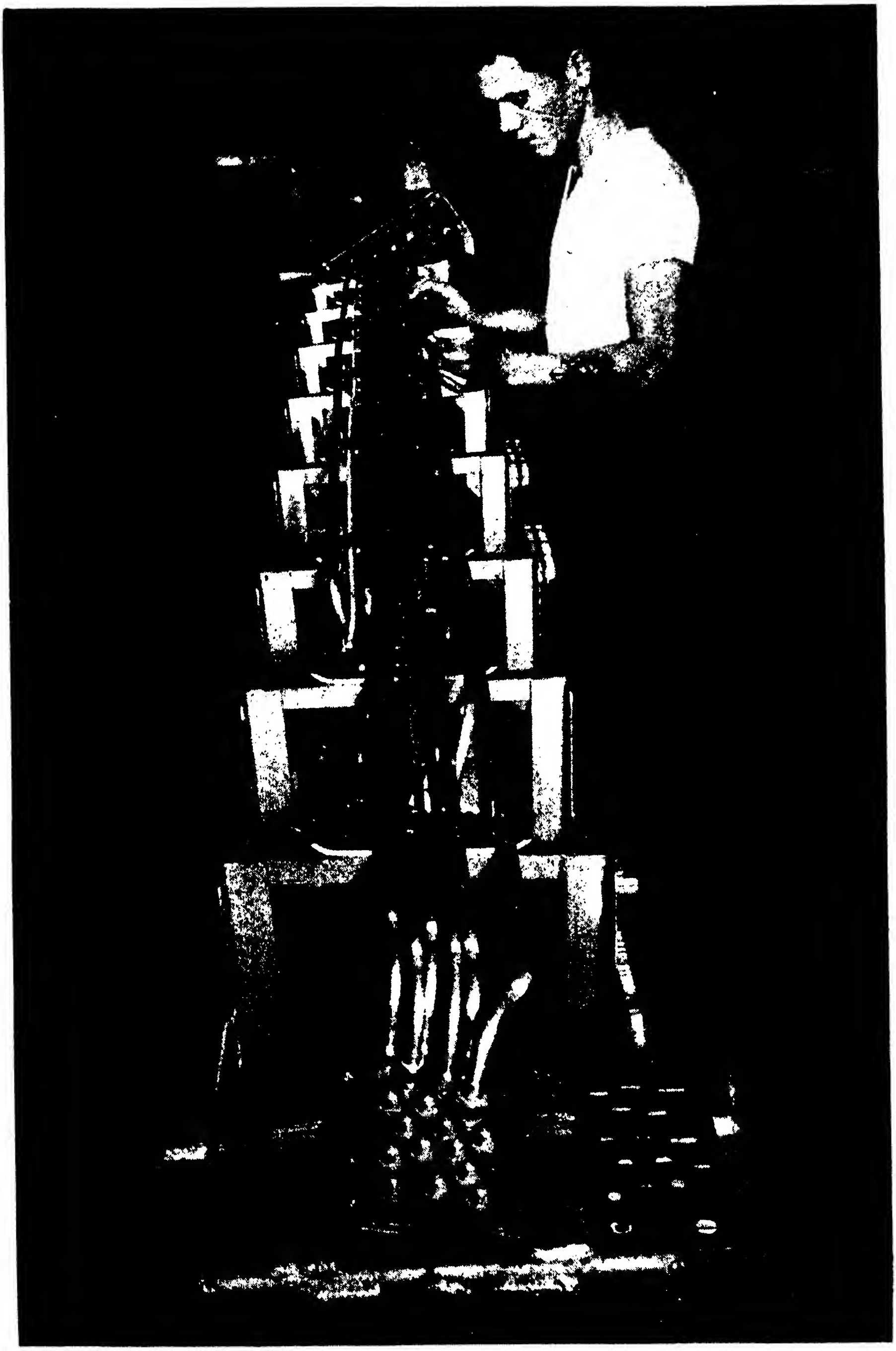


FIG. 43. Bench Assembly Fixture.

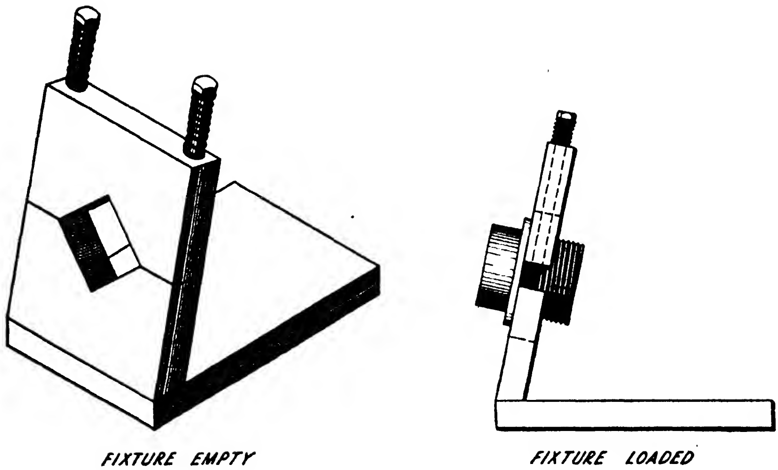


FIG. 44. Detail Assembly Fixture.

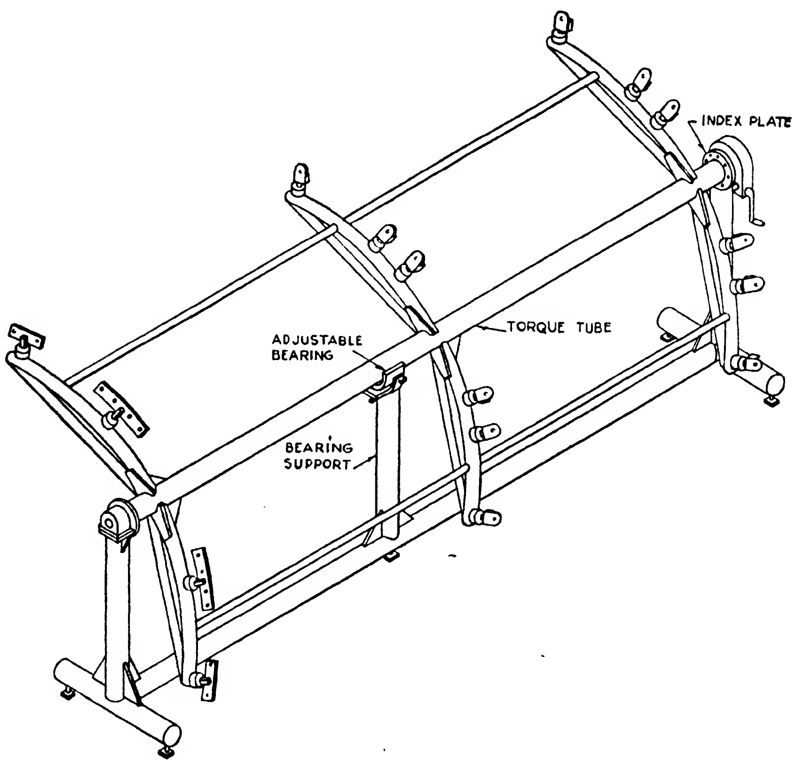


FIG. 45. Single-beam Jig.

alter the attitude of the work, it may be more aptly termed a *torque-beam* jig or fixture.

(5) *Three-dimensional jigs or fixtures.* These jigs or fixtures are the more complicated assembly tools, used when the assembly is such that a general-parts layout in only two dimensions is impractical. A very large three-dimensional jig or fixture is frequently called a *buck.*

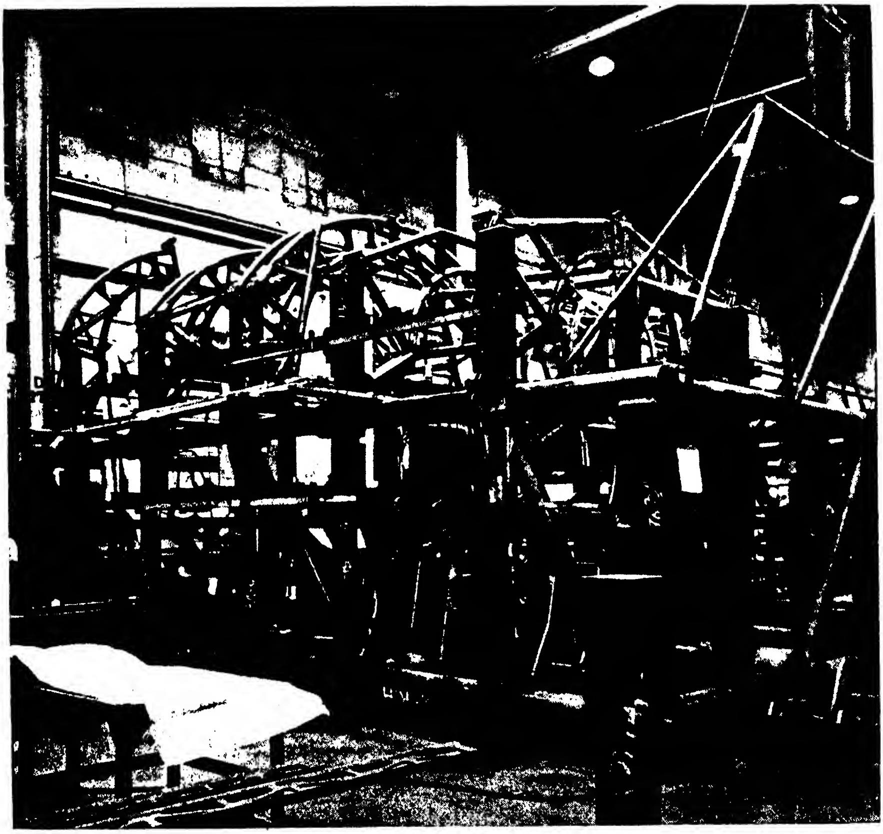


FIG. 46. Buck.

Fig. 46 shows a buck which has been used in building the major portion of a large airplane fuselage as a single unit. Tools of this type are not often used for mass production, because their lack of accessibility gives them a very low efficiency rating.

Automatic Jigs

Although they are rather expensive, automatic jigs are particularly useful in mass production because they automatically locate and clamp

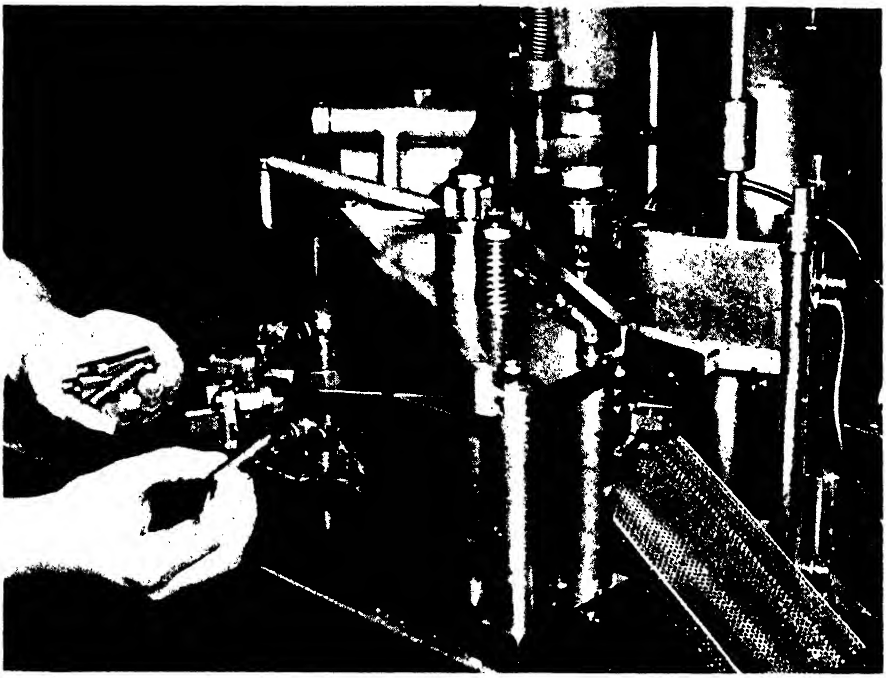


FIG. 47. Automatic Jig.

the work in place. They have been extensively used in the automotive industries.

An automatic pin drilling and burring jig is shown in Fig. 47. This tool even ejects its own chips. An operator is required only to load it with pins. When the cycle of operations is complete, the individual pins fall down the chute at the right.

Boring Jigs

Boring jigs are commonly used for machining holes which must be aligned and sized with particular accuracy, or which are too large for drilling. They may also be used in finishing two or more holes in the same line.

Where these tools are employed, the boring operations are generally performed by boring bars with inserted cutters of various sizes. The boring bar is usually guided by two bushings, one on each side of the bored hole and located as close as possible to each end of the hole. The bar is rotated and simultaneously fed through the work, or the work with its jig is fed over the rotating bar. This may be accomplished in a regular boring lathe, in horizontal boring or drilling machines, or in a radial drill.

The boring jig body may be either a solid piece or a combination of members. Since the strain on such tools is frequently considerable, the body should be rigidly designed so that its members will permit the least possible spring. Also, because boring jigs must be securely fastened to machine tables, each tool of this type should be provided with convenient and accessible clamping devices.

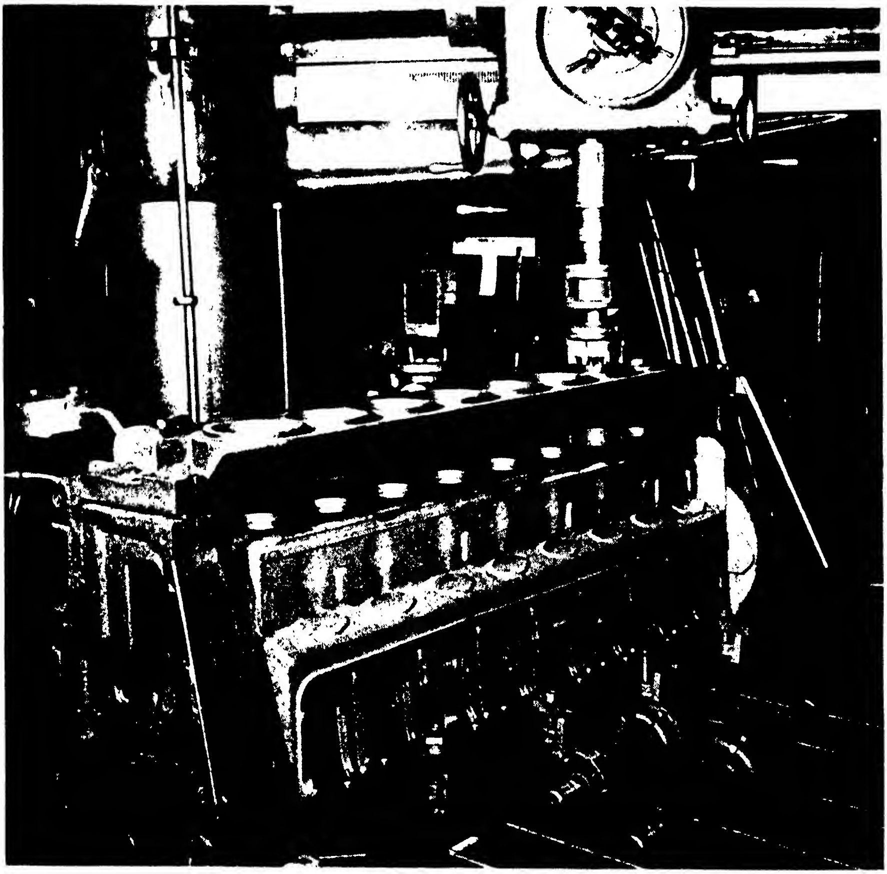


Fig. 48. Boring Jig.

Fig. 48 shows a boring jig used to bore for cylinder liner sleeves in a medium-size Diesel engine block. Note that the bushings are so located that they will have a substantial bearing in the jig body. Smaller boring jigs may be provided with tongues or lips on the surfaces which are clamped to the machine table, so that the machine operators can quickly locate each tool in the correct position. Further, it is often efficient and economical to provide small boring jigs with feet so that

they can be used on a regular drill-press table—that is, when the holes to be bored can be opened with a drill piercing the base material.

The guide bushings of boring jigs are of the same general types as the bushings for drill jigs. They may be made of either cast iron or steel. They should be ground to fit the boring bar, which is also ground, and they should be long enough to insure good bearing.

Broaching Fixtures

Most broaching (the enlarging and dressing of holes) can be accomplished without special fixtures, a hardened bushing which fits into a hole in a machine table being all that is generally necessary. However, on vertical machines, it is sometimes preferable to slide the work over the leading edge of the broach and, in such cases, fixtures are desirable.

For example, when the bottom of the keyway in a taper hole is required to be parallel to the taper, a fixture such as the one shown in Fig. 49 may be used. Here a work-locating spigot is arranged with its axis at an angle to the center line of the tool and broach guide so that the work will be held in the required position. Because the fixture is flanged and increased in diameter, and because a locating peg is provided, the keyway may be positioned radially with regard to the holes in the flange.

Spigots alone sometimes serve as fixtures for broaching keyways, as indicated in Fig. 50. The rear portion of the illustrated fixture is fitted into a hole in the machine table, and the flat undersurface is positioned against a shoulder or plate to prevent movement. A component (represented by phantom lines) is push-fitted over the front end of the fixture, and the bottom of the groove within the fixture controls the depth of the keyway—since the total depth of the groove plus the depth of the keyway equals the maximum depth of the broach at its largest end. If a hardened shim is placed in the bottom of the fixture groove, it becomes possible to cut a keyway deeper than the total cutting depth of the broach. A lip on the shim should bear against the end of the spigot and keep the shim from being pulled through the slot by the friction of the broach.

Combination or Indexing Jigs or Fixtures

Combination or indexing jigs or fixtures are those tools which can be individually used to accomplish two or more operations. The former may be distinguished from the latter by the fact that the indexing group normally utilizes special index mechanisms, such as were discussed in Chapter 3.

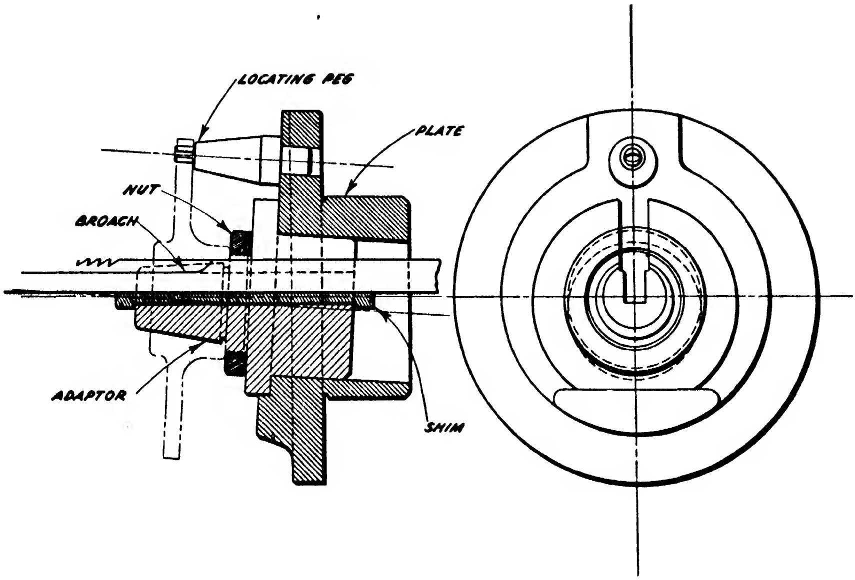


FIG. 49. Broaching Fixture.

Fig. 51 shows a combination fixture which is capable of performing two operations without the aid of a special indexing device. Powered by an arbor press, this tool is used to press and stake bearings in bearing plates.

A jig which can perform three operations without the use of an indexing device is shown in Fig. 52. This tool is used by a large stove manufacturer for the purpose of assembling, drilling, and trimming

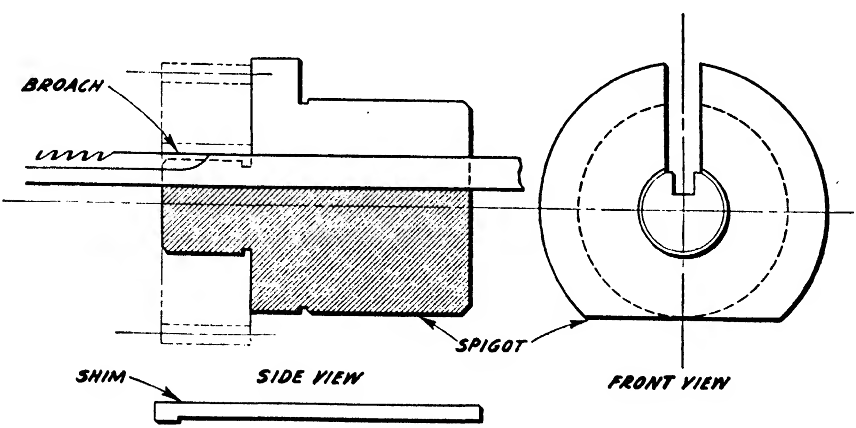


FIG. 50. Spigot Used as a Broaching Fixture.

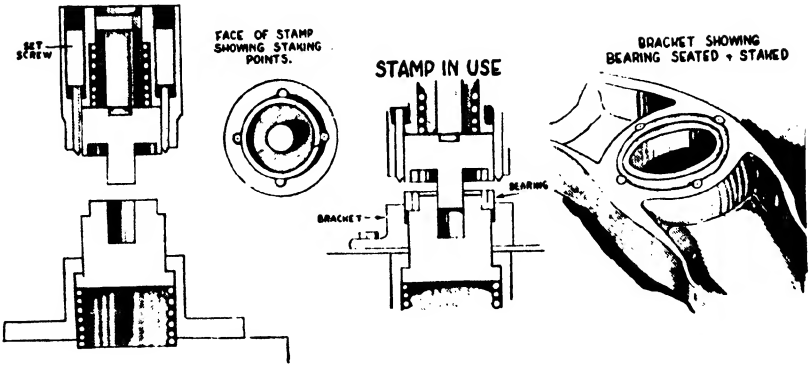


Fig. 51. Combination Fixture.

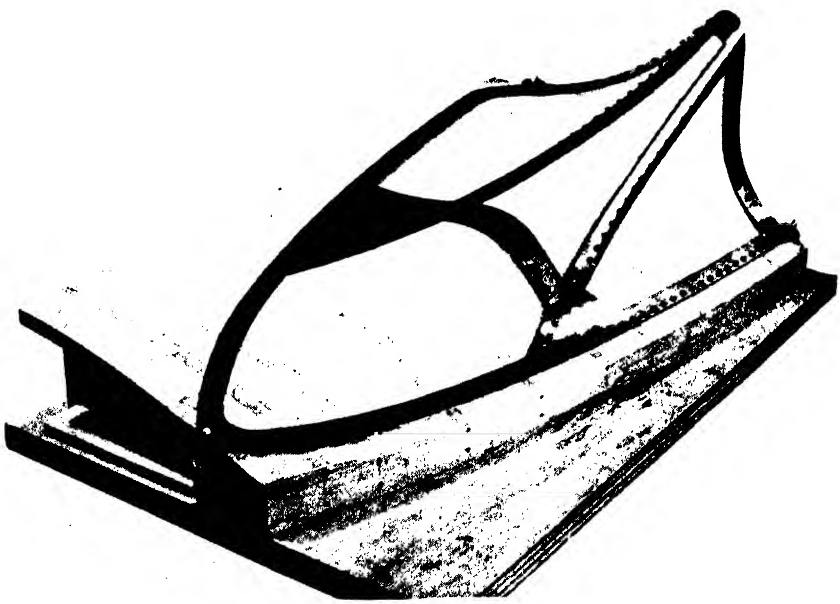


Fig. 52. Combination Jig.

drop-hammered sheet-metal parts. The wooden base of the tool has the exact shape of the parts which are to be assembled. When the parts have been properly positioned on this base, they are locked in place by a drill-jig frame. Holes are drilled in the parts through bushings in the frame, after which the parts are trimmed along the edges of the base and the frame is removed to permit assembly of the parts by riveting and bolting.

Drill Jigs

Drill jigs are used almost exclusively for drilling, reaming, tapping, countersinking, and facing. Whenever more than one of these operations are required on a single piece of work, it is usually most practical and economical to accomplish all of the operations in a single tool, using

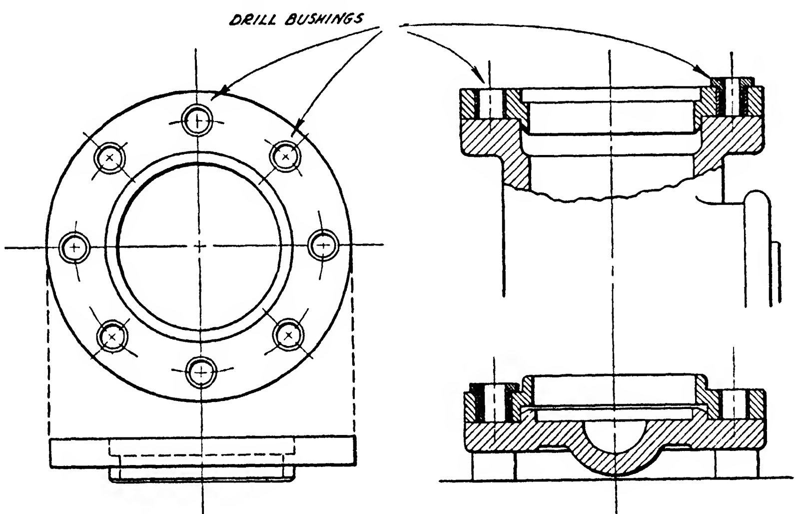


FIG. 53. Open Drill Jig. *Left:* Jig. *Right:* Jig in use.

slip bushings or index mechanisms. In certain unusual circumstances, it may be necessary to use separate jigs.

The two general types of drill jigs are known as the *open* and the *closed* types.

Open drill jigs are sometimes called *clamping* jigs. Their bushings are normally in the same planes, or parallel with one another, and they are not provided with removable walls or leafs. The work may be inserted without moving the parts of the tool, and the jig may be held to its work by means of straps, bolts, or clamps. The jig may be fitted into or over some finished part of the work so that it will be properly located

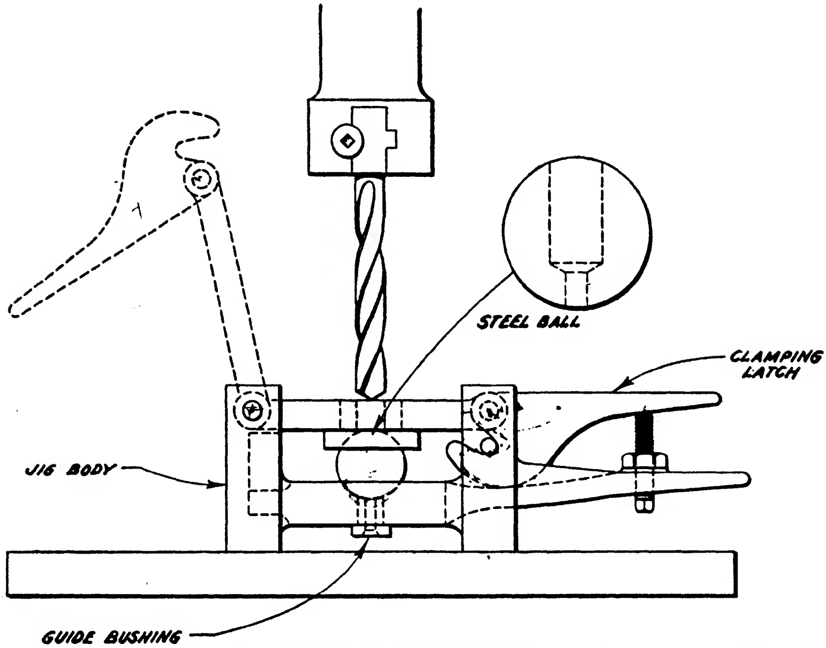


FIG. 54. Closed Drill Jig.

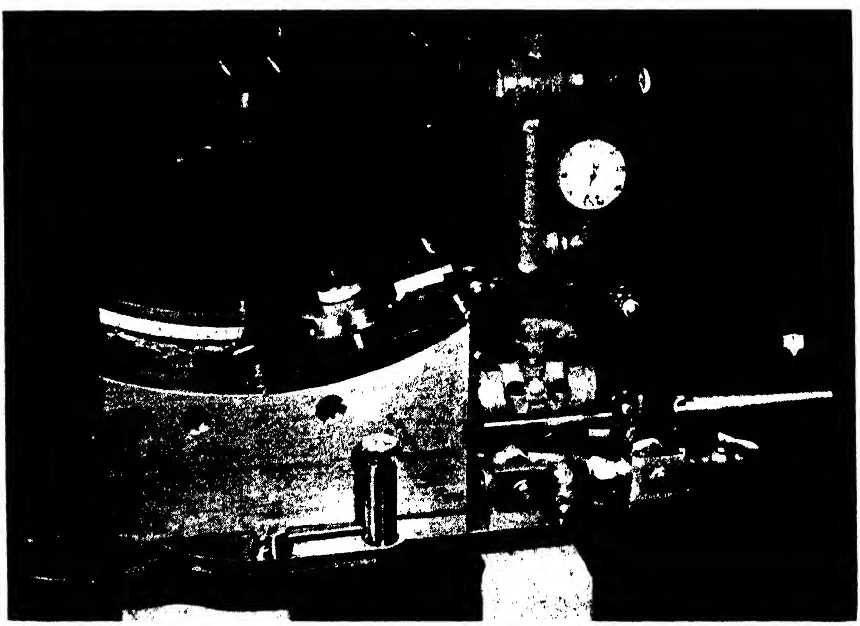


FIG. 55. Grinding-machine Fixture.

and fixed in position. The simplest jigs of this type are merely plates provided with bushed holes which are located to correspond with the required locations for the drilled holes. One of these is shown in Fig. 53. This tool is used in drilling the stud bolt holes in a cylinder flange, and also for drilling the cylinder head which is bolted to the cylinder.

Closed drill jigs are sometimes called *box* jigs. They are so named because of their appearance, and are used in working on components whose holes must be drilled at various angles to one another. As a rule, a tool of this type can be used only after one or more leafs or covers have been properly adjusted. Sometimes it is necessary to remove a loose wall, which is held in place by means of bolts or dowel pins, in order to locate the work in the jig; and the work is ordinarily held in place by means of screws, screw bushings, straps, or hook bolts. Fig. 54 shows a typical box or closed jig which is used in drilling holes of different diameters in steel balls.

Grinding-machine Fixtures

Grinding-machine fixtures are used to hold parts which must be machined by grinding to extremely accurate dimensions—engine connecting rods, bevel gears, crank pins, valve faces, and camshaft flanges.

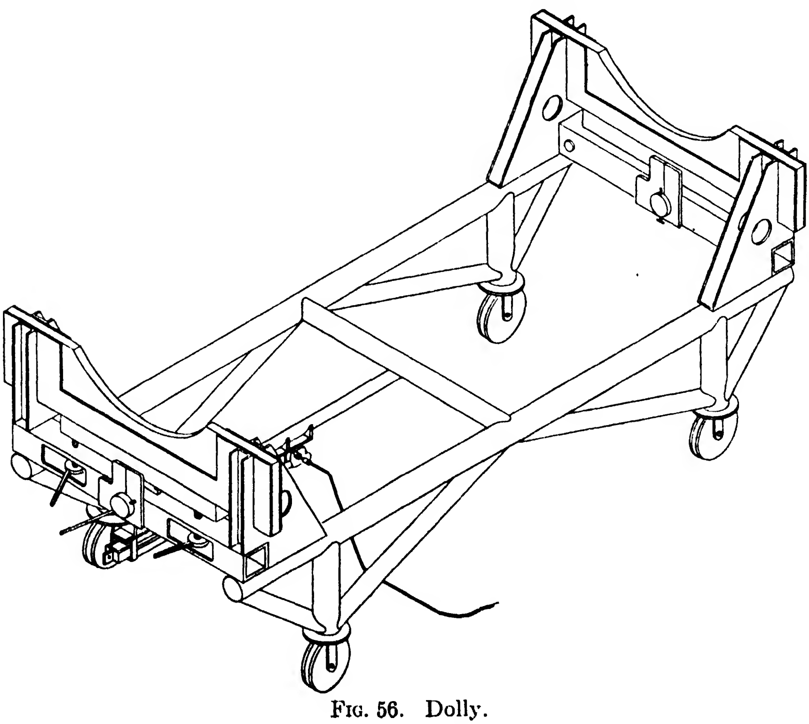


Fig. 56. Dolly.

Fig. 55 shows a grinding-machine fixture which is used to grind two 11-inch spherical radii on a level switch.

Handling Jigs or Fixtures

Handling jigs or fixtures are primarily designed for use in moving large components or partly complete assemblies from one location to another. They are best known as *dollies* and *cradles*.

A typical dolly is shown in Fig. 56. Tools of this type are towed behind a truck or similar vehicle. Because they are extremely accessible, they may also serve as assembly tools for the installation of small furnishings. Care should be taken to avoid the installation of top-heavy or protruding details on dollies. When the dolly is used in connection with an assembly that is awkward to handle, it should be provided with sufficient adjustment to facilitate loading and unloading. Since rigid construction is not a matter of prime importance in a tool of this type, a dolly usually comprises a series of vertical supports tied together through the center with a horizontal beam which has bracing suitable to provide stability. Holding devices are used to maintain the position of the work in the tool, and each part should be positioned or held so that it will not be damaged.

Cradles are virtually the same as dollies, except for the fact that they must be moved by means of a crane or hoist rather than a ground-based vehicle. Accordingly, they should be designed so that they can be easily balanced. A typical cradle is shown in Fig. 57.

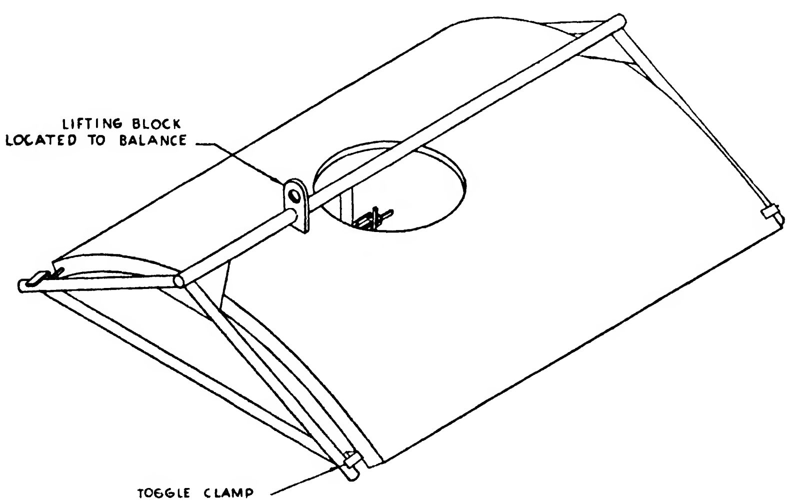


FIG. 57. Cradle.

Inspection Jigs or Fixtures

Inspection jigs or fixtures are tools used to determine whether components or assemblies have been manufactured with satisfactory precision. They are sometimes called *testing* or *checking* jigs or fixtures.

Fig. 58 shows a pair of *air-test fixtures* which are used to check for leaks in a series of six-arm intermediate impeller drive shafts, each of which has six radial oil holes. The function of these fixtures is to seal the drive shaft holes so that compressed air can be injected into each shaft. If the shaft shows no signs of air leakage while in one of these fixtures, the inspector can be reasonably certain that it will not leak oil when in actual operation.

An inspection jig, used in testing valves, is shown in Fig. 59. This tool will check three dimensions simultaneously.

Fig. 60 shows how a very simple checking fixture may be used in conjunction with a gage to determine the concentricity and over-all dimensions of a series of small shafts.

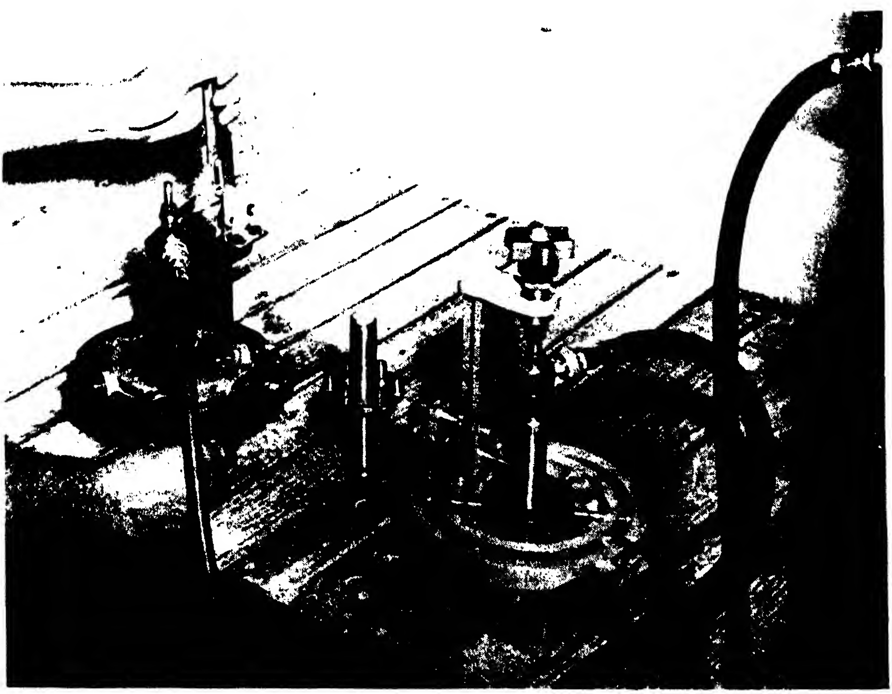


Fig. 58. Air-test Fixtures.

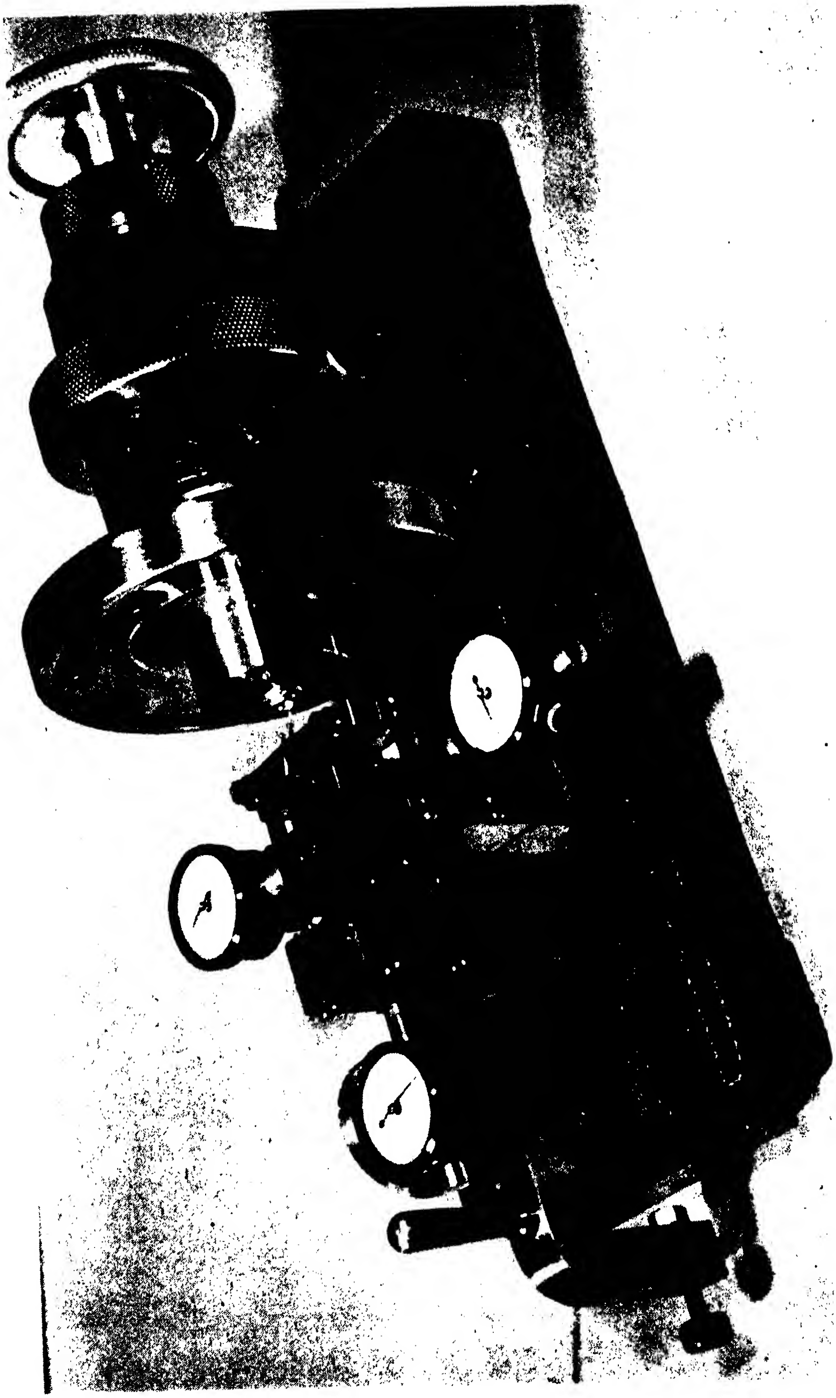


Fig. 59. Inspection Jig.

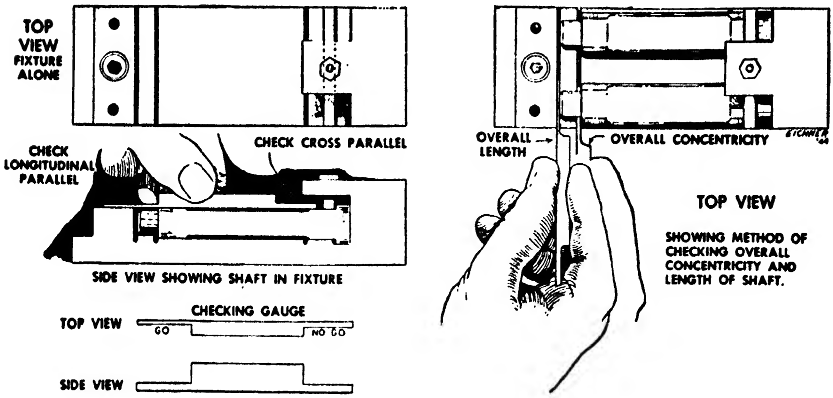


FIG. 60. Checking Fixture.

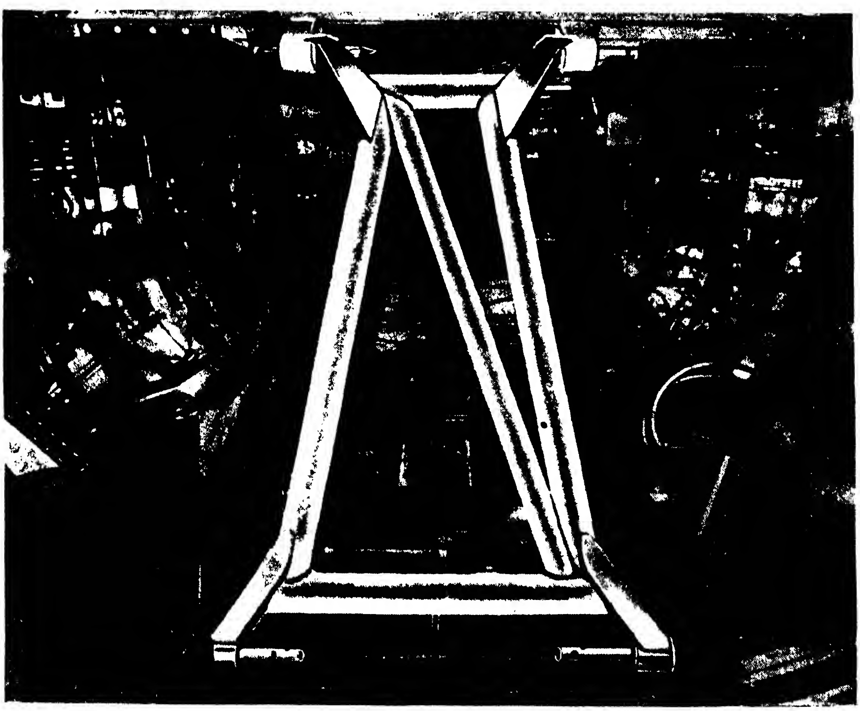


FIG. 61. Alignment Jig.

Locating Jigs or Fixtures

Locating or *alignment* jigs or fixtures are closely related to assembly tools because their primary purpose is to facilitate the accurate locations of parts. However, they do not always have provisions for clamping or holding the components, and they may be used for disassembly as well as for assembly.

A typical alignment jig is shown in Fig. 61. The purpose of this tool is to maintain the relative positions of four vital fittings while the nose landing gear of a large airplane is removed, repaired, and replaced.

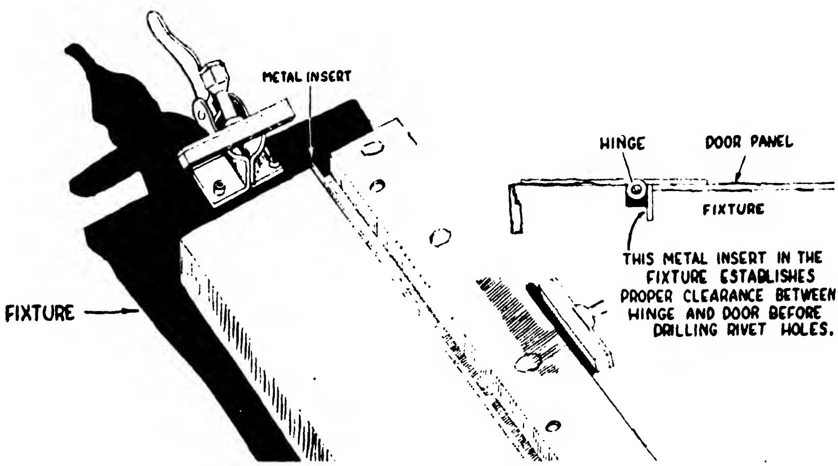


Fig. 62. Locating Fixture.

Fig. 62 shows a locating fixture which is used to establish the proper distance between a metal door and its hinge prior to drilling and riveting the two parts.

Milling Fixtures

In addition to those holding tools used in connection with milling machines, the fixtures for planers and shapers may be generally classified as *milling* fixtures.

The simplest form of milling fixture holds and locates a single component in the course of a single operation in a milling machine. More complicated tools of this type may hold duplicate castings or forgings in a variety of positions, either for milling surfaces which are at an angle or for milling at various points around a circular part. Accordingly, some milling fixtures control the paths followed by their cutters, and others are designed to give the work a rotary feeding movement

FIG. 63. Milling Fixture.

(for example, as when milling a curved slot or groove on a cylindrical part).

One of the more complicated milling fixtures is shown in Fig. 63. This rotary tool is particularly useful because it enables a single machine to mill cylinder heads continuously without pauses during which the operator makes new setups.

Generally speaking, planing fixtures do not have to be constructed as strongly as ordinary milling fixtures, because they are not used in making such heavy cuts. They may be provided with setting pieces or

templates which will set the cutting tools so that the work is always machined in a certain relation to the locating means on the fixture itself.

Shaping fixtures are essentially the same as planing fixtures, except that each shaping fixture must be designed to hold the work in a single position.

The most commonly used fixture for planing, shaping, or milling is the *vise*. Frequently the regular vise jaws are replaced by false jaws, which may be fitted with locating pins or seats and held together like regular jaws.

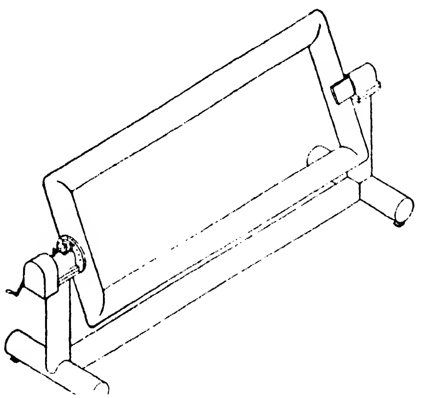


FIG. 64. Fixture with Trunnion.

Trunnion Jigs or Fixtures

Almost any jig or fixture can be equipped with a trunnion, when it is necessary to increase the accessibility of the tool.

For example, Fig. 64 shows a picture-frame assembly fixture which is equipped with a trunnion so that its frame can be rotated through 360 degrees. The purpose of this was to make the upper and lower components in the tool separately accessible to workmen standing on the factory floor.

The mechanism of a large fixture trunnion is indicated in Fig. 65.

Universal Jigs or Fixtures

Universal jigs or fixtures are those tools which can be used in accomplishing a variety of jobs. Probably the most common tool of this type is the universal drill jig.

Fig. 66 shows a universal drill jig which can even be used in place of a boring mill. This tool has an adjustable base which can be lowered or elevated to the desired height of the hole, and a drill bar with a flat face, which has been ground to exactly half the over-all diameter. A protractor is used to set the drill bar at the proper angle, and set screws are used to hold the bar in this position. Thus it becomes possible to drill holes in parts with numerous different shapes to a tolerance of plus or minus 0.001 inch.

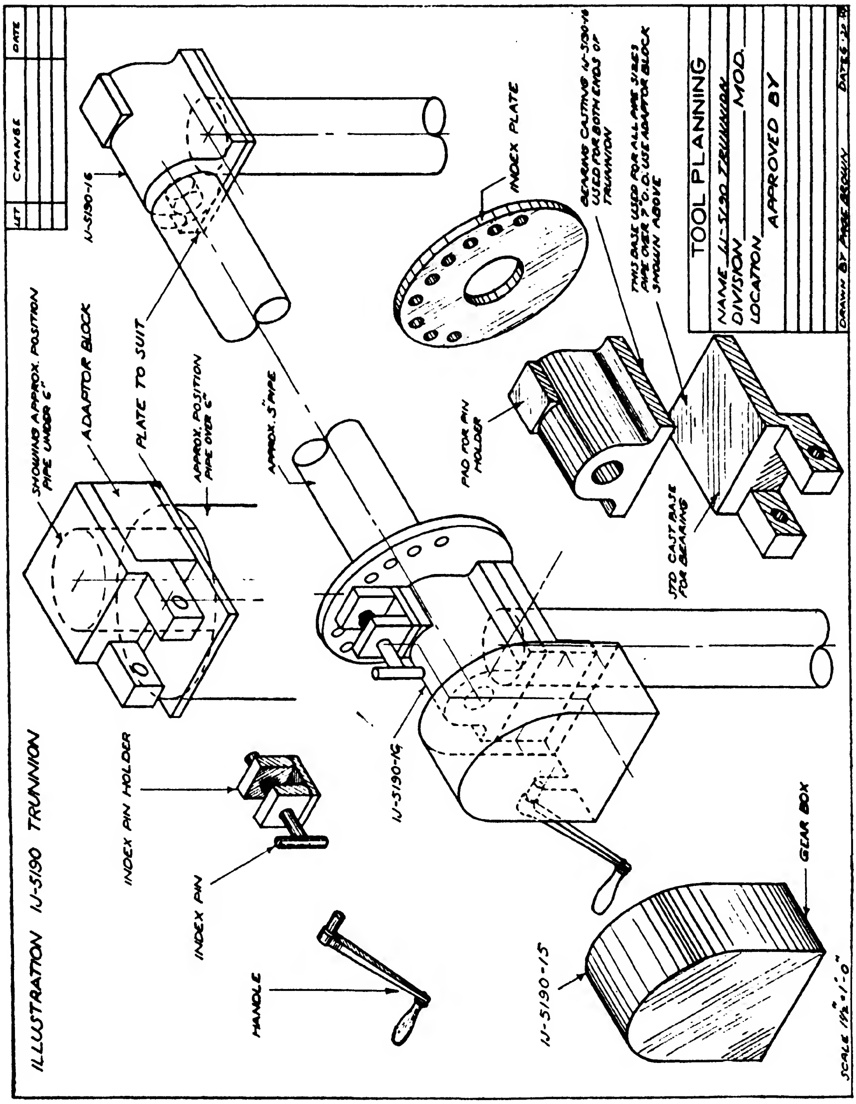


Fig. 65. Trunnion Details.

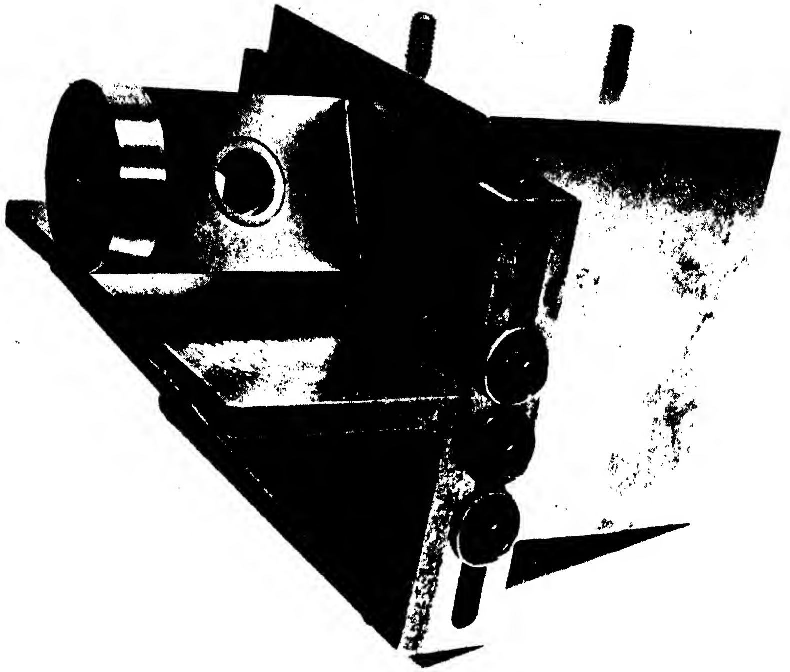


FIG. 66. Universal Drill Jig.

CHAPTER 5

MASTER TOOLS

Need for Masters

IN ORDER to mass produce a large number of articles with essentially the same physical characteristics, it is necessary to utilize a single "master" article which will serve as a standard for replicas. For example, if we wished to produce a series of sheet-metal parts with identical curvatures, we would first have to construct a *master contour model* from plaster or similar material; then we would use the model to make molds or female patterns, in which dies would be cast for the purpose of forming the parts in a hydropress or under a drop hammer.

The need for masters is particularly urgent when it is necessary to duplicate jigs or fixtures, because it is economically impractical to construct identical tools which will produce interchangeable parts without foolproof instruments for controlling dimensions. Therefore, we have *master tools.*

The two general types of master tools are commonly known as *tool masters* and *control masters.*

Tool Masters

The primary function of a tool master is to provide the means for accurately positioning the locating elements of a given jig or fixture. Hence, it is normally the exact opposite of the jig or fixture and it may be called a *master gage* or a *work master.*

Fig. 67 shows the relationship of a very simple jig and its tool master. Note that where the locating element on the jig is a male part, the corresponding element on the master is a female part—and *vice versa.* In this particular instance, the function of the master is to space and align the lugs on the jig.

Often enough, the over-all appearance of a tool master is the same as that of the part which is to be assembled or fabricated in the jig or fixture. For example, Fig. 68 shows the tool master for a fixture which has been used in assembling metal doors.

In other cases, the tool master merely reproduces the locating points or "critical areas" of the part which is to be assembled or fabricated in the jig or fixture. For example, Fig. 69 shows a layout of tool masters which have been used in making jigs for assembling the empennage of a large airplane.

ADVANTAGES OF TOOL MASTERS

Before tool masters were developed, it was extremely difficult and expensive to duplicate accurate jigs or fixtures because it was impossible for toolmakers to work consistently at subvisual tolerances with ordinary positioning or measuring equipment. This obviated the possibility of efficient mass production, because efficient manufacturing methods are largely dependent upon tolerances. If an article is constructed with more than necessary precision, production time is wasted almost the same as if the work were accomplished with insufficient accuracy; and, if *consistent* tolerances cannot be observed in the construction of duplicate tools or parts, all the advantages of interchangeability are lost. Accordingly, tool masters were created to serve as gages. They are better than other types of gages for duplicating purposes, because their accuracy is not dependent upon manual adjustments for each series of operations.

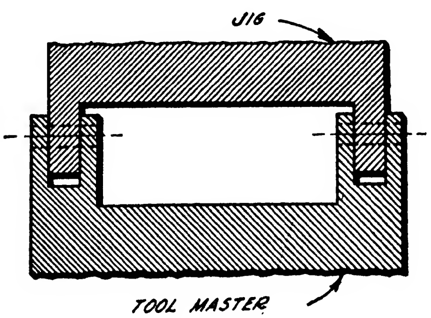


FIG. 67. Simple Jig and Tool Master.

The tolerances observed in the manufacture of tool masters are dependent only upon the tolerances required in fabricating or assembling finished parts. Regardless of how small these tolerances may be, tool masters enable workmen to transfer a single set of dimensional peculiarities to an unlimited number of duplicate jigs or fixtures in a minimum amount of time and without a large accumulation of errors.

USE OF TOOL MASTERS

Jigs or fixtures must be duplicated whenever identical parts are to be fabricated or assembled in more than one location. When identical jigs or fixtures are needed in more than one factory, it is often best to construct all of the tools in a single plant so that one layout of tool masters may be utilized. The object of this procedure is to insure the dimensional consistency of all identical parts.

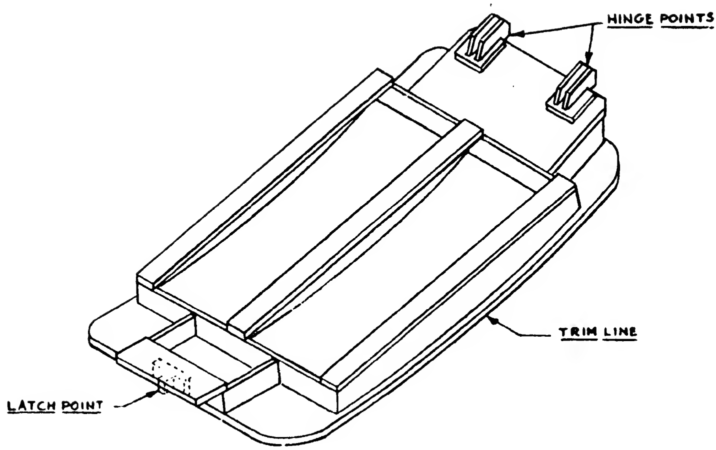


Fig. 68. Tool Master for Metal Door Fixture.

When it becomes necessary to ship a jig or fixture from one plant to another, there is always the possibility that the accuracy of the tool will be impaired before it reaches its destination. Therefore, the receiving plant must be provided with accurate means for checking the tool. This may be accomplished by shipping a sample part or the tool master along with the duplicate jig or fixture. When the tool master is shipped, it is generally most economical to construct the duplicate tool therefrom at the receiving plant.

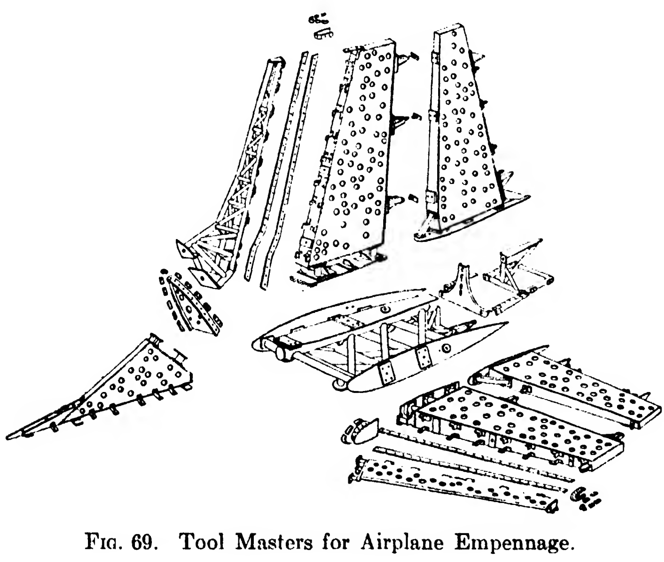


Fig. 69. Tool Masters for Airplane Empennage.

TOOL MASTERS FOR INSPECTION

In many large factories, it was at one time customary to wait until some trouble in co-ordination was experienced before a check was made of a jig or fixture. But now this practice is generally neither economical nor expedient, because tool masters make it possible for tool proofers to check each jig or fixture at specified intervals with both speed and efficiency.

Besides saving the time that might be lost because of defective workmanship, this inspection eliminates the expense of scrapping or salvaging valuable materials.

TOOL-MASTER STRUCTURES

Since they must retain their predetermined dimensions within close tolerances, tool masters should always be structurally stable and capable of withstanding all the rough handling and loads that may be imposed upon them.

The design of the tool-master structure should be such that critical "face-to-face" dimensions can be transferred to jigs or fixtures by means

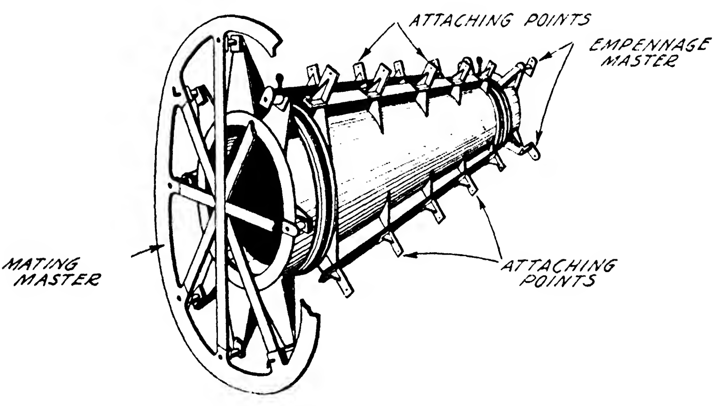


FIG. 70. Fuselage Tool Master.

of ordinary feeler gages, because this will facilitate reworking due to engineering changes and speed the inspection of production tools.

The male fittings of the tool master should be made to the top limits of the male fittings of the component (and, conversely, the female fittings of the tool master should be made to the bottom limits of the female fittings of the component) so as to prevent interference fits, which would cause the production tool to be improperly co-ordinated with the component.

Fig. 70 shows an exceptionally strong and stable tool master which has been used in duplicating assembly jigs for the aft end of an airplane fuselage; it is a semimonocoque structure with welded-steel construction. Because they can be used in reproducing different types of small jigs or fixtures, the parts of a large tool master like this one may be given different names—such as *mating master* and *empennage master.*

Control Masters

When duplicate jigs or fixtures must be constructed in a number of different factories, it is necessary to supply each plant with an identical set of tool masters. *Control masters* are used to make these identical tool masters. A control master may be either an extremely accurate production tool or a special *contributory tool* which has little resemblance to an ordinary jig or fixture.

Those production tools which serve as control masters are commonly called *master jigs* or *master fixtures,* and are preferred by some manufacturers because they can be used directly on an assembly line after the mastering program is complete.

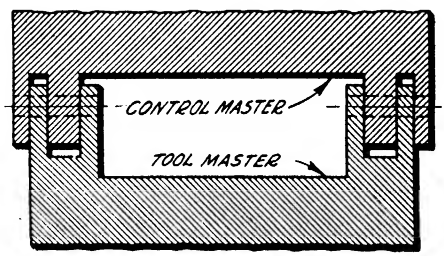


Fig. 71. Grand Master and Tool Master.

The contributory tools which function as control masters are sometimes called *grand masters* or *master masters.* In mass production, they may be superior to master jigs or fixtures because their structures are especially designed for the rapid reproduction of the various tool masters. Fig. 71 indicates the relationship of a grand master and a tool master. Compare this with the relationship shown in Fig. 67.

In any event, the control master represents the locating elements of a production jig or fixture. For this reason it can also be used to check the accuracy of a tool master, a component, or an assembly.

CONSTRUCTION OF CONTROL MASTERS

Either the control master or the tool master may be constructed first, depending on the urgency with which the first production jigs or fixtures are needed. If time permits, the control master is usually built first; but if there is a rush to get into production, the tool master is of more immediate value.

The control master, whenever it is constructed, becomes the origin of all dimensions within its control. It is used primarily to construct

tool masters; and since it is a precision tool, it should be handled with considerable care.

The structural stability and tolerance requirements for control masters and tool masters are essentially the same.

Co-ordination

When mentioned in connection with tooling, the term *co-ordination* usually refers to an ideal state in which all holes are properly aligned, all tools are correctly dimensioned, all components are interchangeable, and the like. Therefore, when we hear of a well-co-ordinated tooling program, we realize that the program is reasonably close to technical perfection.

Although they are not by any means in universal use, tool masters and control masters facilitate the establishment of a well-co-ordinated mass-production tooling program by making it possible for tool fabricators to obtain all their basic information from a single dependable source.

For example, the control of the dimensions between holes in two mating parts can be most readily established by means of the mating portion of a tool master, from which drill jigs for both parts can be constructed. This eliminates the possibility of variations in the locations of holes, because the required dimensions for the separate units come from a single source.

Similarly, control masters may be utilized to co-ordinate adjacent tool masters and their mutual critical points. Sometimes, in fact, a single control master may establish all the dimensions required in constructing tool masters for an entire structure. When this is possible, the co-ordination of production tools and parts is almost unavoidable.

CHAPTER 6

MASTER TOOLING DOCK

Purpose

ALTHOUGH THE master tooling dock was primarily designed to serve as a positioner for the locating elements of assembly jigs or fixtures, it has a variety of interesting features which might be of value to any manufacturer whose production depends upon the development of precise and co-ordinate tools and gages.

Besides eliminating the need for many of the complex mastering tools described in the previous chapter, the master tooling dock can be universally applied to the work of grid-line scribing, constructing "mock-ups" (or contour models), tool proofing, and jig boring. It can be utilized rapidly and efficiently by semiskilled workers, and it permits automatic co-ordination in the manufacture of either prototype or production tools.

Essentially, the master tooling dock is a mechanical means for projecting the two-dimensional (or flat) master layouts of a streamlined body into the third dimension without a loss of accuracy. Figs. 72, 73, and 74, respectively, show how the bodies of an automobile, a railroad car, and a motorboat might be faired in conformity with the lines of a grid plane system as a series of flat master layouts.

In the master tooling dock, the grid lines of the flat master layout are represented by a series of physical members called *straightedges*. There are four longitudinal straightedges to represent station lines or length dimensions; two vertical straightedges to represent water lines or height dimensions; and one or two transverse straightedges to represent buttock lines or width dimensions.

Fig. 75 indicates the nomenclature of a large version of the master tooling dock.

Physical Characteristics

The base of a master tooling dock is of particular importance, because the accuracy of any large tool is dependent upon the nature of its foundation; and, as previously explained, the characteristics of a

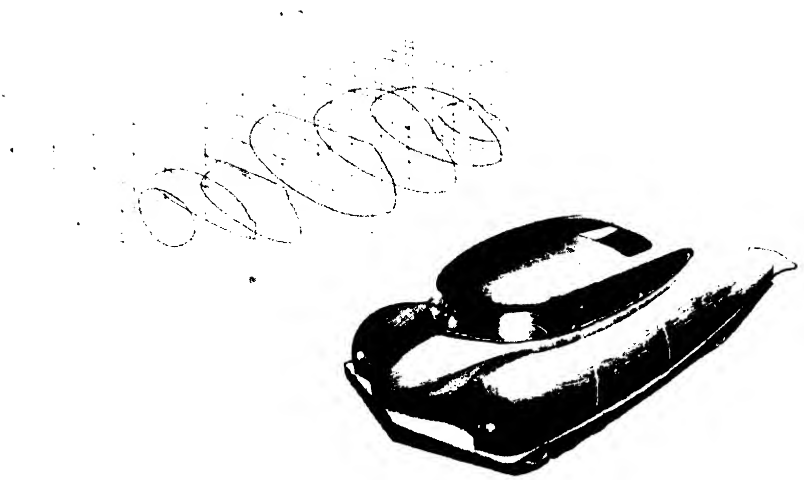


FIG. 72. Grid Line Layout for an Automobile.

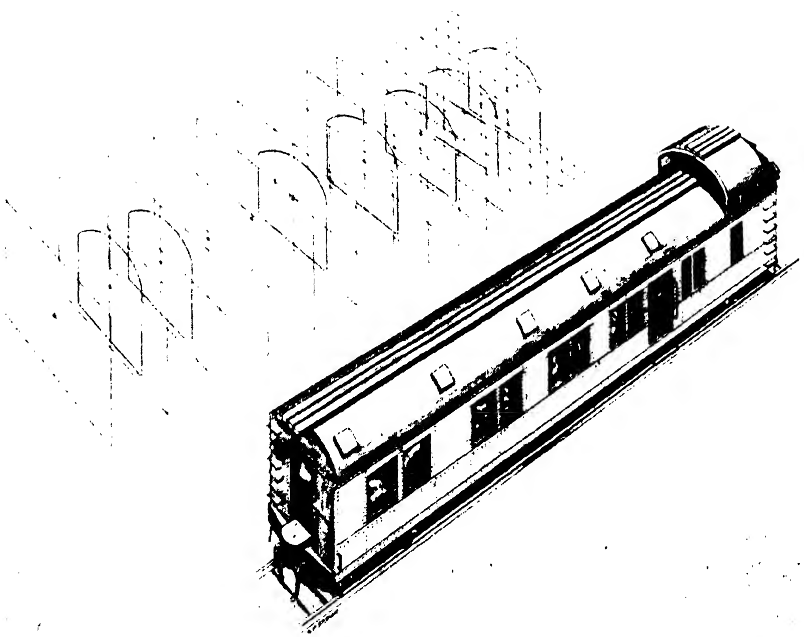


FIG. 73. Grid Line Layout for a Railroad Car.

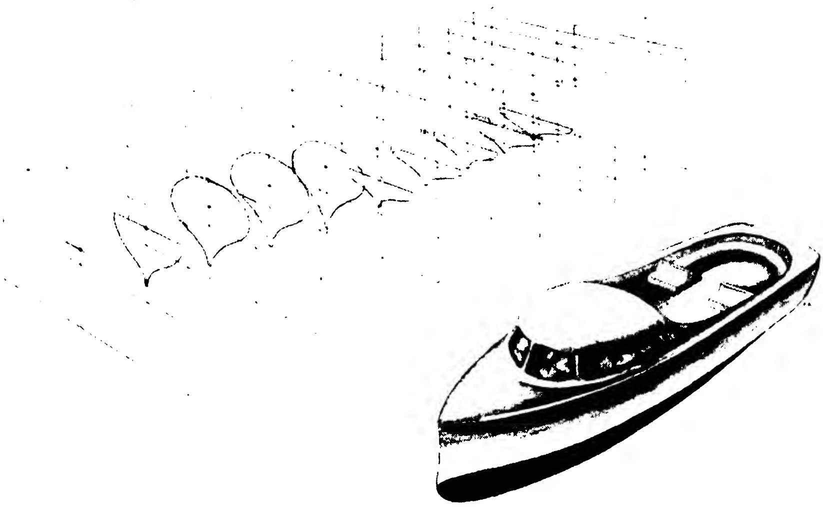


FIG. 74. Grid Line Layout for a Motorboat.

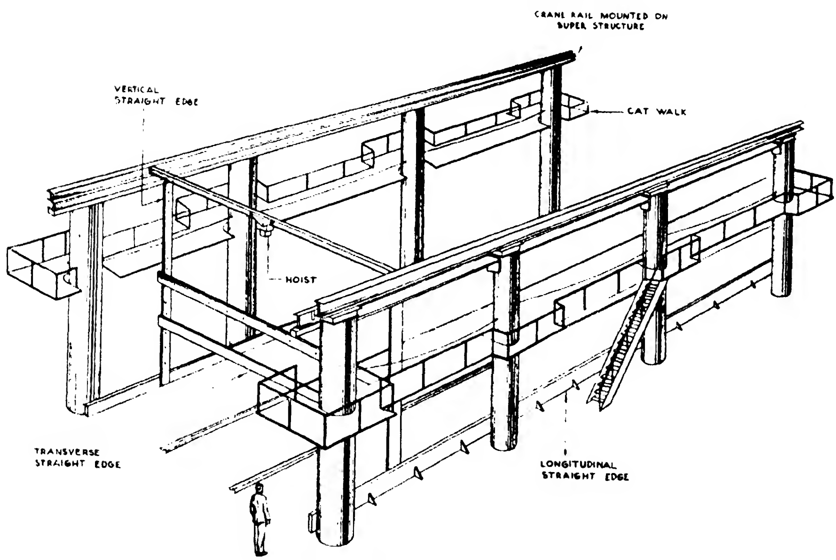


FIG. 75. Nomenclature of a Large Master Tooling Dock. (General view of a 60-foot dock.)

supporting structure depend largely upon the features of the locality in which it is situated. Fig. 76 shows the cross section of a dock which was erected in a coastal area, where the ground is subject to changes due to both tidal movements and earthquakes. The base is of reinforced

concrete, completely independent of the surrounding building structure and supported by pilings driven into solid earth (which is at a depth of approximately 40 feet).

Embedded in the base are loading rails, which may be used to locate the rough structure of a jig or fixture during set-up operations, and a

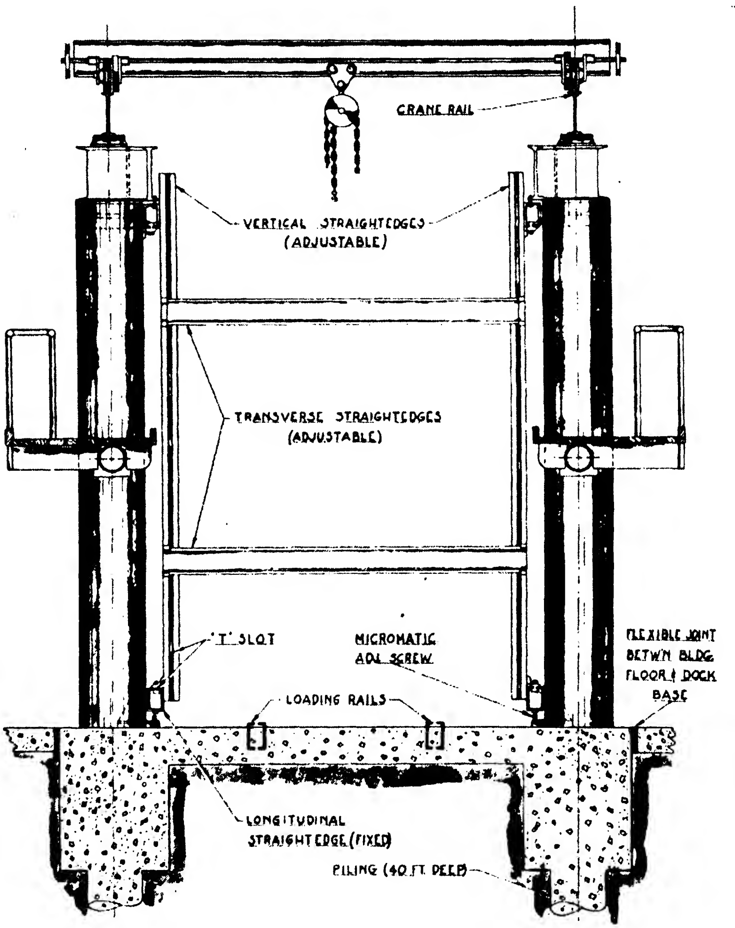


FIG. 76. Cross Section of a Master Tooling Dock.

series of vertical columns, which are large-diameter steel pipes filled with concrete and bonded to the base with reinforcing steel. The columns carry a structural steel superstructure which supports the upper longitudinal straightedges, crane rails, and catwalks. The lower longitudinal straightedges are supported directly from the base by angle

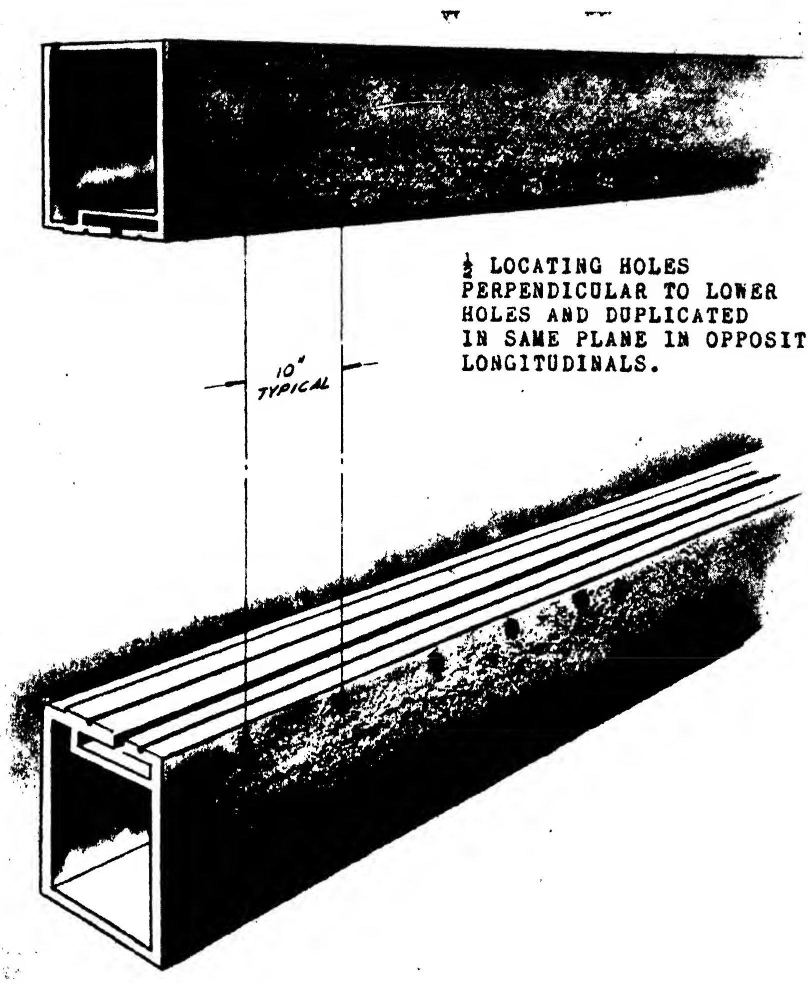


FIG. 77. Longitudinal Straightedges of Tooling Dock. (For purposes of clarity, only two of the four longitudinal straightedges are shown.)

blocks, which are fastened to the base by studs sunk into the concrete.

All four of the longitudinal straightedges are secured by micrometric adjusting screws, which may be used in aligning the straightedges in true parallel relationship with one another. The alignment is accomplished within exceedingly close tolerances by means of electrically energized wires, an electronic mercury level, and master gages.

Since they are movable, the vertical and transverse straightedges are dependent only on the alignment of the longitudinal straightedges for

the relative accuracy of their positions. Physically, they have three major features in common with the longitudinal straightedges:

(1) Each straightedge has a series of 0.5-inch diameter bushed holes at 10-inch intervals, evenly spaced on a single edge as indicated in Fig. 77. The centers of these holes represent the locations of grid lines or planes. The holes are numbered for reference and identification; and, owing to the extreme accuracy of their 10-inch locations, they are used as the basis for all positioning.

(2) Each straightedge has a T slot running its full length for use in clamping certain accessories, once they have been positioned.

(3) Each straightedge has a ribbed working surface, which has been carefully machined and then scraped or ground to reduce surface irregularities.

It has been found that the fixed longitudinal straightedges can be aligned to a tolerance of ± 0.001 inch up to lengths of 60 feet. If the foundation of the dock is adequate, this alignment will not vary more than 0.002 inch in a period of three months.

The working capacity or size of a master tooling dock is determined by the lengths of its straightedges. Because of machining limitations, it has been found advisable to make the straightedges in units with lengths of not more than 20 feet, even though their total lengths may be considerably more.

The master tooling dock shown in Fig. 75 has vertical straightedges 15 feet high, transverse straightedges 10 feet wide, and longitudinal straightedges 60 feet long. Accordingly, it has a 15′ by 10′ by 60′ working bay or envelope. The smallest dock yet constructed has a working bay or envelope of 20′ by 8′ by 6′.

Dimensional Control

Either strip templates or microbar-type location gages may be used to provide dimensional control for establishing the positions of the movable straightedges of the master tooling dock. When speed alone is the most essential tooling requirement, the microbar is used; but when strict parts interchangeability is necessary, or when a number of duplicate jigs or fixtures must be produced, the strip templates are preferable.

Strip templates are ⅜″ by 2″ by 51″ cold-rolled strips of steel. In one margin of each strip, 0.5-inch diameter holes are jig-drilled at 10-inch centers, so as to match the grid holes in the straightedges, upon which the strip template is mounted by means of ground pins. In the opposite margin, holes are jig-bored to the precise offsets called for by

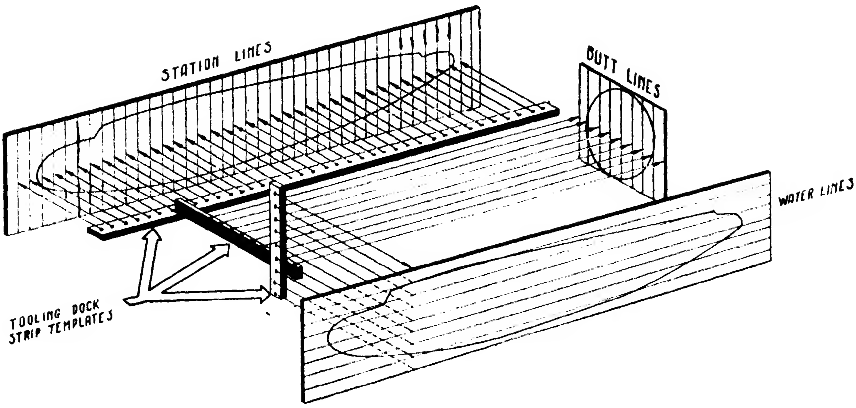


FIG. 78. How Strip Templates Provide Dimensional Control.

the basic dimensions of the article to be constructed. Fig. 78 shows how the latter holes can reproduce the basic dimensions of an airframe. Strip templates can be fabricated as soon as the basic dimensions of a product are determined; and their number is proportional to the overall length, breadth, and height of the product. Each strip template can be identified and classified by stencil markings and conveniently stored in an ordinary filing cabinet, as shown in Fig. 79.

It has sometimes been found economical to utilize a microbar location gage in place of strip templates, since a single microbar can be used for all straightedge positioning. However, the microbar is not as dependable as a strip template because it must be reset manually by means of

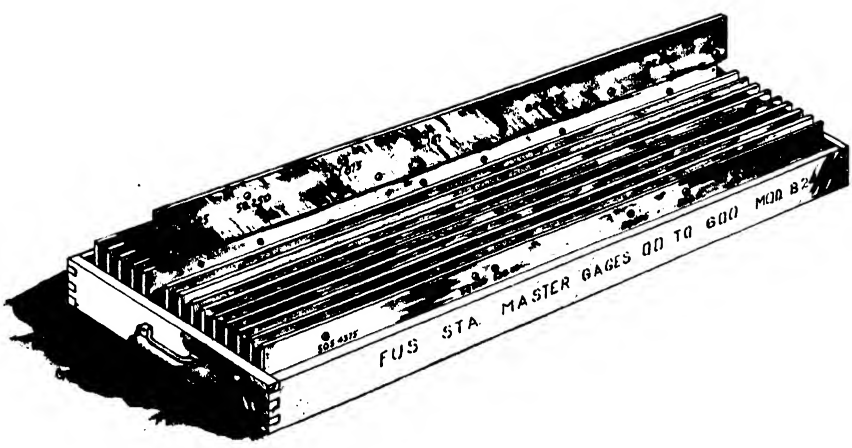


FIG. 79. Strip Templates in Filing Cabinet.

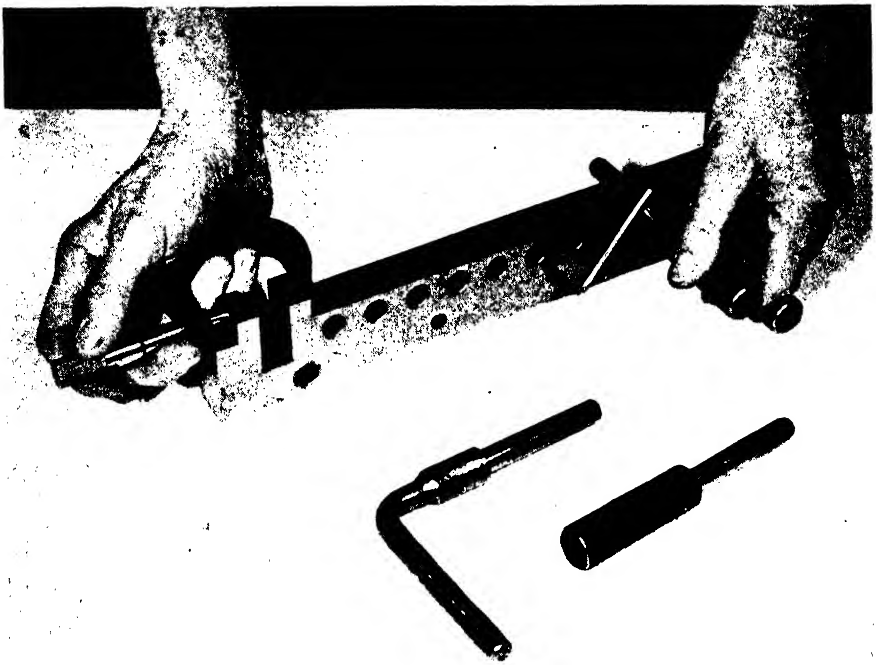


Fig. 80. Microbar.

a micrometer for each individual positioning operation; and this, of course, brings human fallibility into the work. Fig. 80 shows a microbar of the type that has been commonly used in connection with the master tooling dock.

Operation of the Master Tooling Dock

For ordinary jig or fixture positioning operations, ten simple steps are required to utilize the master tooling dock. They are:

(1) A jig or fixture frame is moved into the area between the longitudinal straightedges by means of an overhead crane. (*See* Fig. 81.)

(2) The frame is positioned in accordance with the reference lines of the dock by means of the loading rails and supporting devices attached thereto. (*See* Fig. 82.) The loading rails consist of two pairs of steel channels, spaced so as to admit the use of T bolts, and the supporting devices are usually clamps or braces, which can be securely bolted to the rails.

(3) A strip template is used to position fittings, which will establish station locations when fastened with appropriate bolts to the T slots of the longitudinal straightedges. (*See* Fig. 83.) The same strip tem-

FIG. 81. Moving a Jig Frame into the Master Tooling Dock.

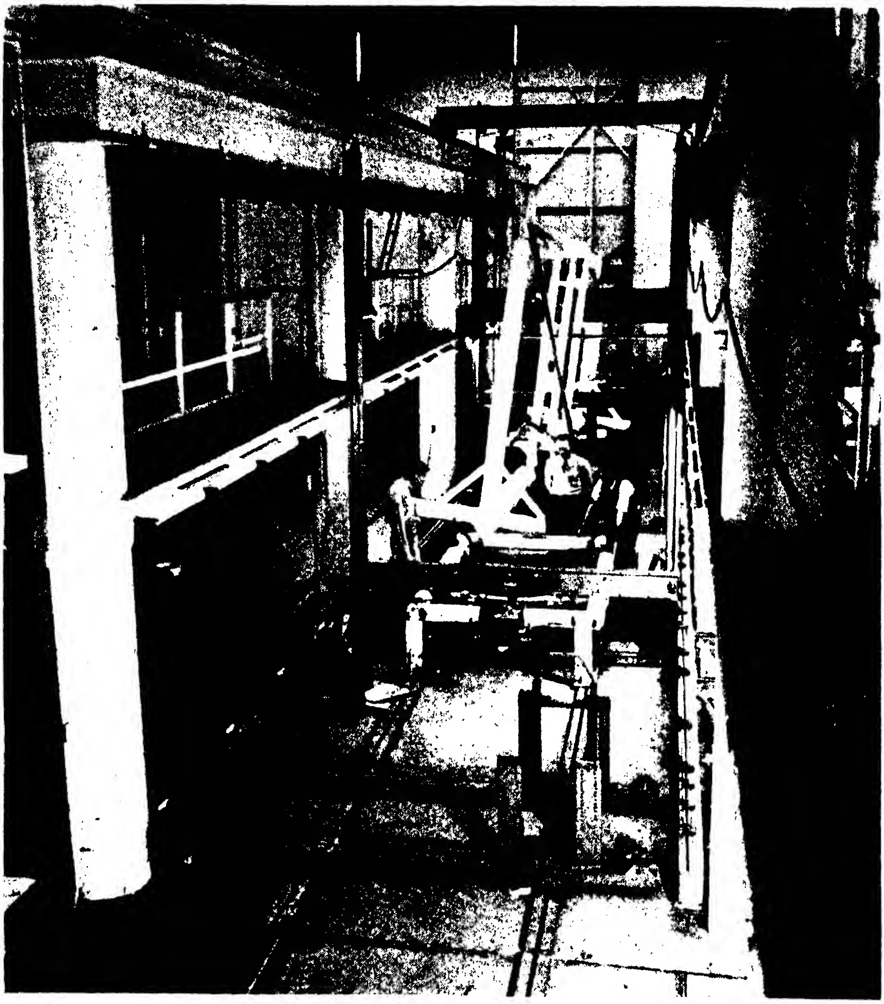


FIG. 82. Positioning Fixture Frame in Master Tooling Dock.

plate can be used to find identical station locations on all four longitudinal straightedges.

(4) The jig or fixture frame location is tool proofed. (*See* Fig. 84.)

(5) By means of the overhead crane, the vertical straightedges are moved to the fittings which establish the location of the first station on the longitudinal straightedges. When they have been attached to the fittings by means of ground pins, the first dimension in space is firmly and accurately established. (*See* Fig. 85.) Note that the vertical straightedges simulate the face of a vertical drafting board. A screw

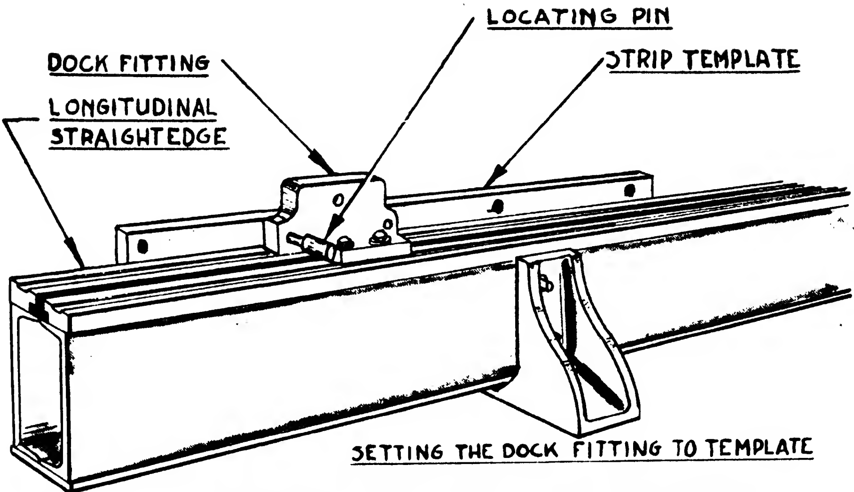


Fig. 83. Using Strip Template to Position Dock Station Fitting.

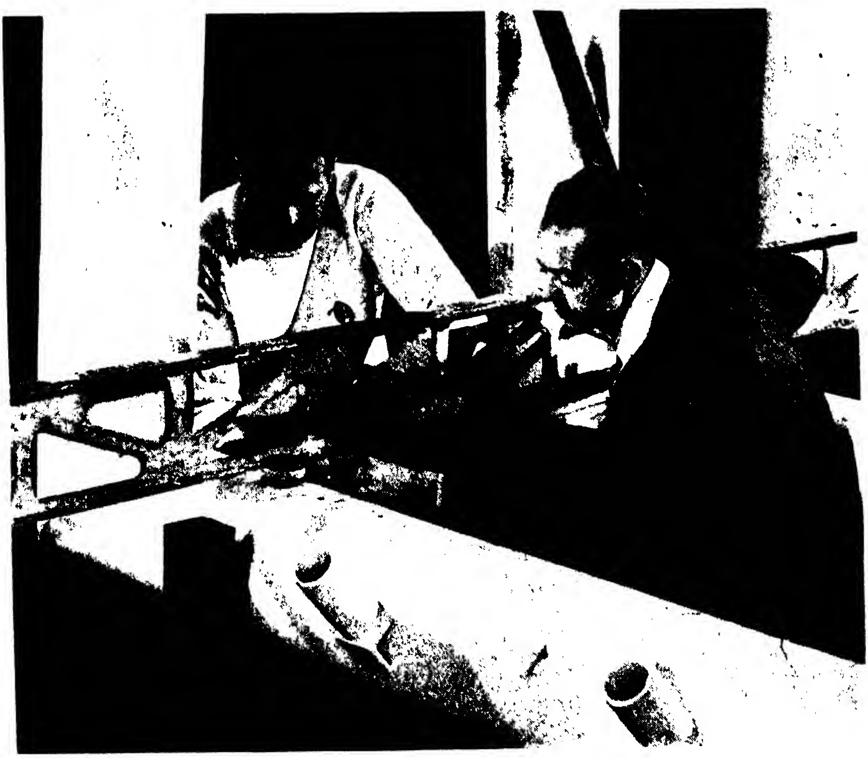


Fig. 84. Tool Proofing Jig or Fixture-frame Location.

jack at the foot of each vertical straightedge permits adjustment, so as to relieve any strain that might be imposed on the longitudinal straightedges; this unit should be adjusted until the ground pin turns freely in the bushed hole, which is used to position the vertical straightedge. A machine screw can be inserted through a clearance hole in the center of each station fitting into threaded holes in the vertical straightedge, enabling the latter to be tightened against the face of each longitudinal straightedge.

(6) A strip template is used to find a water-line location on each of the two vertical straightedges, so that additional fittings may be

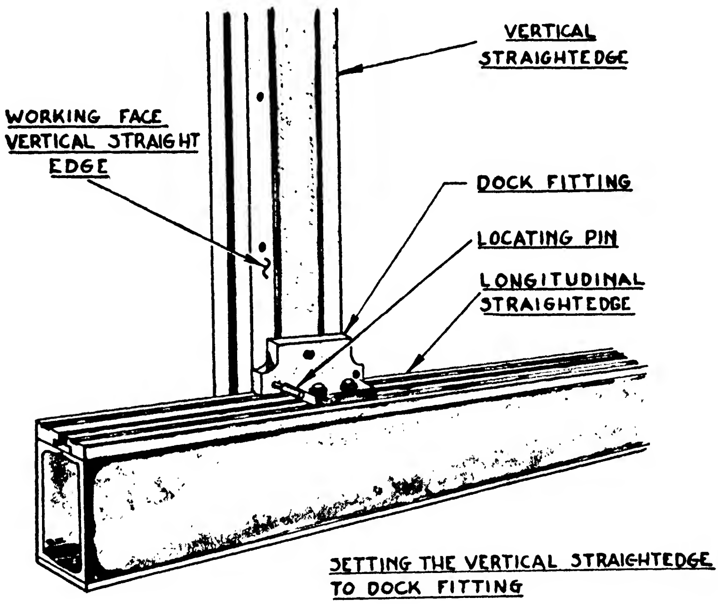


FIG. 85. Positioning a Vertical Straightedge.

correspondingly positioned (by means of T bolts in the appropriate slots) and the transverse straightedge may be positioned at the correct height on the vertical straightedges. (*See* Fig. 86.) One or two transverse straightedges may be used, depending on the nature of the job. The transverse straightedges are analogous to the conventional parallels used on drafting boards, except that their movements are in the perpendicular plane and they establish the second dimension in space. Counterweights inside of the vertical straightedges may be attached to the transverse straightedge by means of cables and pulleys, so that the latter may be balanced for easy operation.

(7) A strip template is used to find a butt-line location on the trans-

verse straightedge, and at this point an ***index fitting*** or ***dummy locator*** is positioned to establish the third dimension in space. (*See* Fig. 87.) Altogether, there are three types of fittings which can be used to establish the third dimension in the master tooling dock. First, there is the index fitting which is used to locate tooling holes on flat surfaces; then

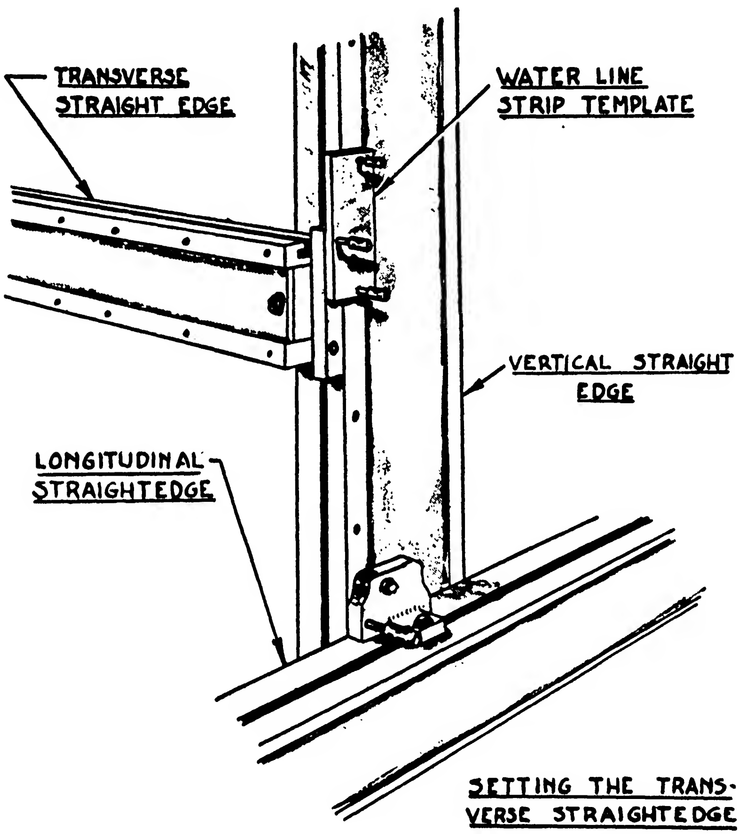


FIG. 86. Finding a Water-line Location in Tooling Dock.

there are two types of dummy fittings, which might be compared with the "mortise" and "tenon" joints used in woodworking (since one is a female and the other is a male). To cope with the many variables that may be encountered, these fittings can be fabricated with a variety of dimensions. However, the dimension of 2 inches is very accurately machined in the dummy fittings so that each may be precisely held for setup and use.

(8) A jig or fixture locator is positioned on the dummy locator or equivalent fitting. (*See* Fig. 88.)

(9) The entire setup is tool proofed. (*See* Fig. 89.) At this point, virtually all tool proofing can be accomplished with plug gages.

(10) The locator is mated with the jig or fixture frame by pouring molten Cerromatrix (a metal alloy with a low melting temperature) or equivalent material into a pot which is attached to the frame so as to surround the locator base. (*See* Fig. 90.)

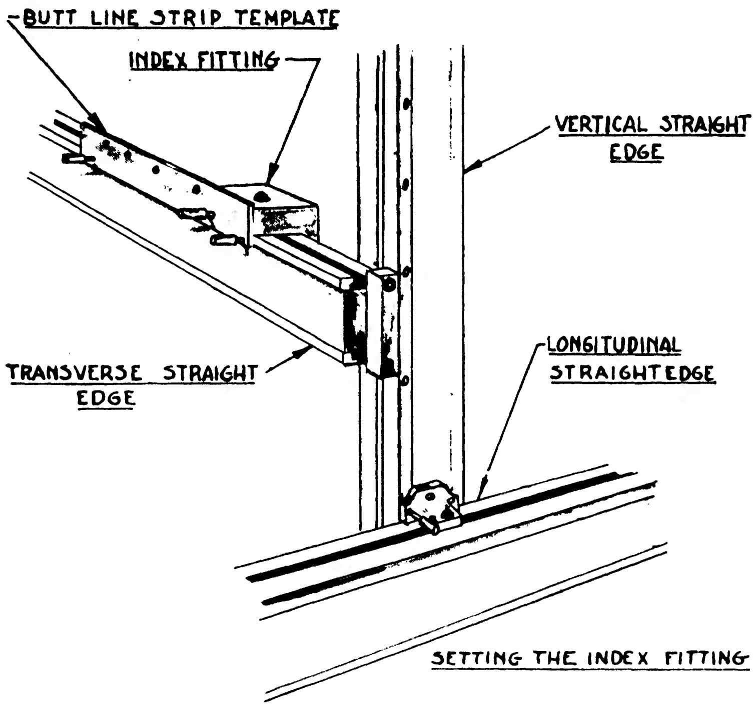


FIG. 87. Establishing Third Dimension in Space.

The last six steps are repeated at each following station until the jig or fixture is complete. Thus, it is now possible to accomplish in only a few hours positioning operations which previously would have required days of difficult work with transits, surface plates, piano wire, oil bobs, scales, height gages, verniers, and similar instruments.

A phenomenon of the master tooling dock is that the tolerances, which must necessarily exist in all settings, are not cumulative. The dimensional control established by the successive use of identical strip templates tends to negate deviations in the various mating assemblies. Therefore, it has consistently been found possible to produce tools well within the tolerances required for successful structural matings. Only a

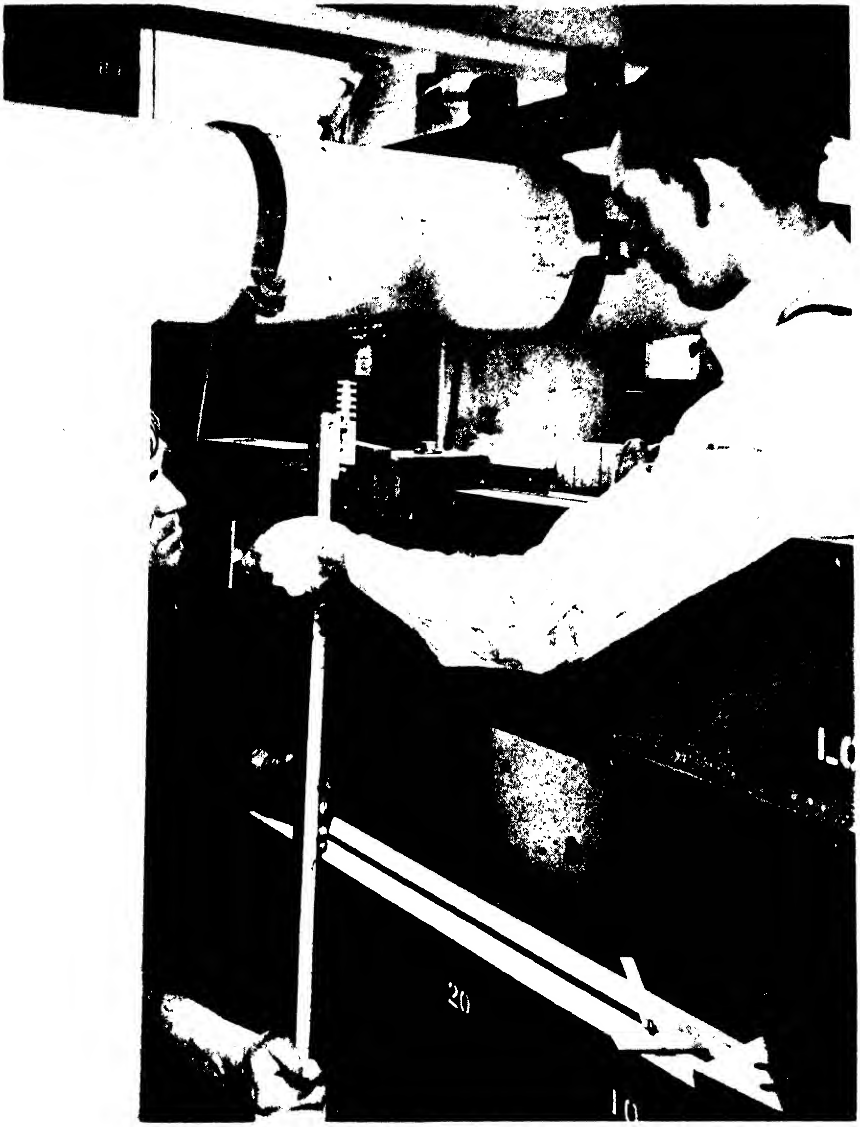


FIG. 88. Positioning Jig or Fixture Locator.

study of engineering requirements can determine the tolerances for any one job; but it may be said that, when matings must be held within limits closer than ± 0.005 inch, the best practice is to set up one side in the tooling dock to the nominal dimensions called out and mate the adjacent side accordingly, using ground pins of extremely close fit.

FIG. 89. Tool Proofing Tooling Dock Setup.

Index Templates

When it becomes necessary to position contour locators in the third dimension, and to establish the relationship between tooling holes in each part to be located in a production tool, an *index template* can be advantageously used in connection with the master tooling dock.

Each index template is made of ⅛-inch sheet steel, with the height and width required for a given tool in accordance with the loft- or body-plan information on a master layout. The layout might therefore be called a *metal layout* of the body plan, except that it has tooling holes instead of contour lines.

The process of fabricating an index template is as follows:

(1) The required number of master metal layouts are photographically reproduced on $\frac{1}{16}$-inch steel template stock, which can be used for further tooling purposes, and thus the *master tooling* layouts are produced.

(2) A master index drill bar is used at the intersection of the grid lines with the principal reference plane of the article to be constructed, so that co-ordinating holes can be drilled at 10-inch intervals in one

FIG. 90. Mating Locator with Jig or Fixture Frame.

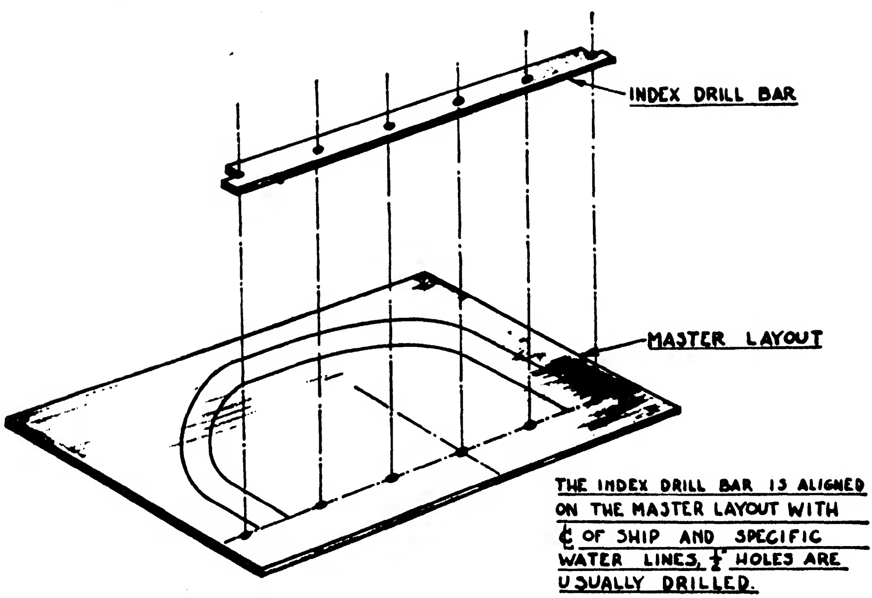


FIG. 91. Use of Master Index Drill Bar.

edge of each master tooling layout and in one edge of the blank index template. (*See* Fig. 91.) The co-ordinating holes are reamed to a diameter of 0.5 inch.

(3) Each master tooling layout is superimposed over pins inserted in the co-ordinating holes of the otherwise blank index template, and exact tooling hole locations are transferred to the index template by stack drilling. (*See* Fig. 92.)

The index template is attached to two transverse straightedges in the master tooling dock, as indicated in Fig. 93, and the tooling holes

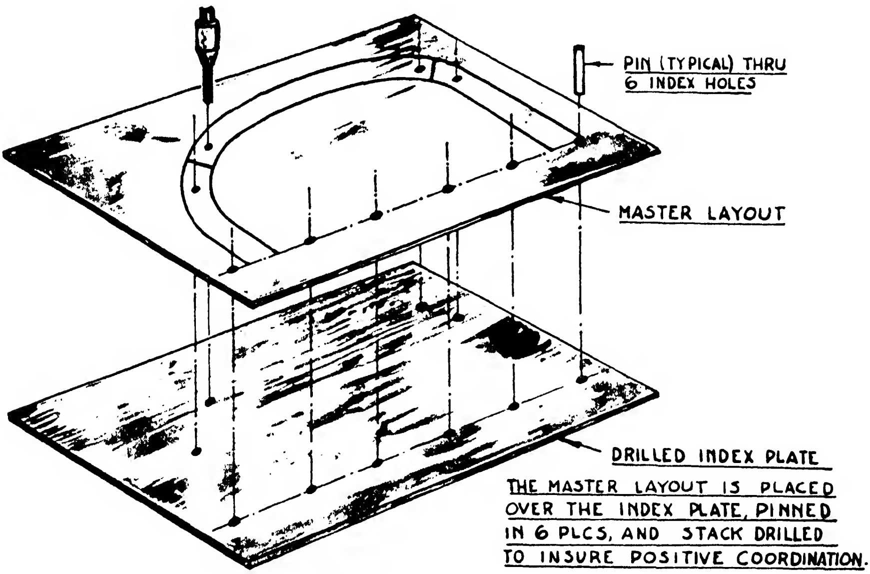


Fig. 92. Stack Drilling Tooling Holes in Index Template.

thereon are directly used to position jig or fixture contour locators. Since this necessitates only variations in the positions of the vertical straightedges, it then becomes possible to move rapidly from station to station in the process of establishing tooling locations.

Because a master layout can be the sole source of reference in fabricating templates for the master tooling dock, complete co-ordination of all tooling holes can be readily attained, making it unnecessary for workmen to refer to drawings in order to ascertain dimensions.

Tool Proofing

Prior to the development of the master tooling dock, jig or fixture tool-proofing equipment included virtually everything from nonprecision tools (such as plumb bobs, squares, and scales) to precision tools

(such as transits, levels, sine bars, micrometers, height gages, and indicators). Each tool had to have its own checking setup, and in some instances it took as long to check as it did to fabricate one of the more complex assembly jigs; then, when the job was finished, the expensive checking setup had to be scrapped.

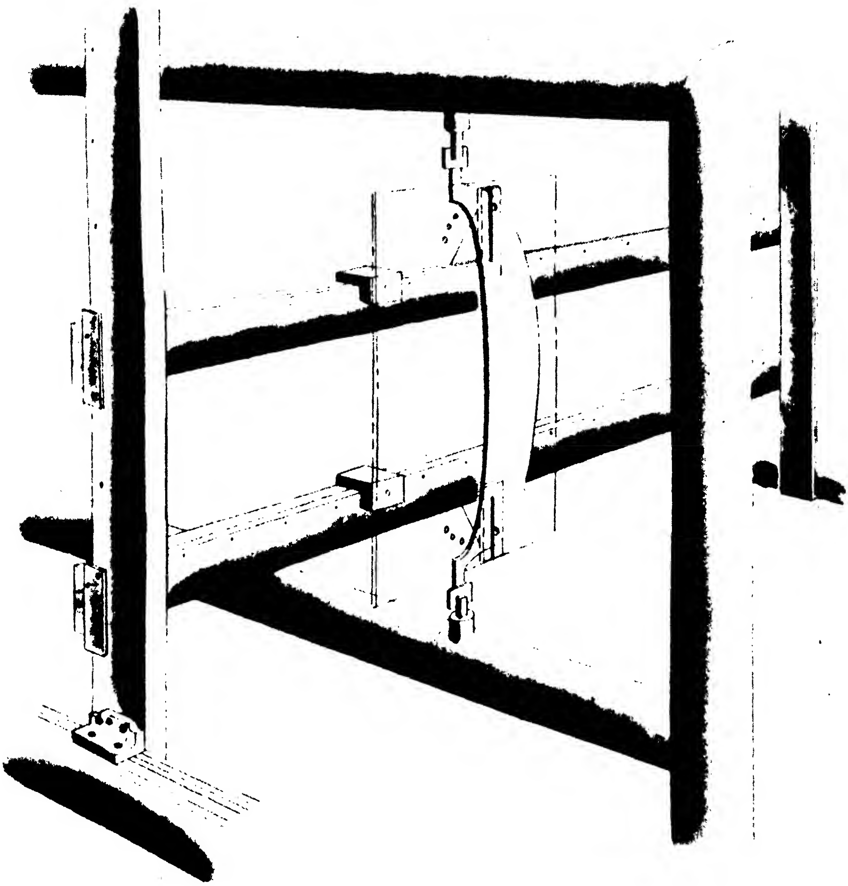


FIG. 93. Index Template in Master Tooling Dock.

In the master tooling dock, only a few standard plug and feeler gages are required for tool proofing. The tool proofer needs only to make sure that locating pins fit freely, that the right accessories are used, and that a feeler will not go between two surfaces when close fits are required.

The master tooling dock itself is the answer to most of its own tool-proofing requirements, because it is a permanent universal tool which

provides a true working surface in three-dimensional planes and because its strip templates provide permanent dimensional control for each jig or fixture.

When index templates are used, tool proofing should begin with inspection and approval of the master layouts. The means of reproducing the layouts should be investigated as to dependability, and those reproductions which are released should be stamped "Approved" by the tool proofers. Because the lines layout of a given template usually establishes the pattern of holes for structural assembly and co-ordination, and because the tolerances required for the cylindrical fits are usually at subvisual limits, it is further desirable to drill and use one of the layouts as a master for reproductions. Inspection for hole layouts may then be physically accomplished by checking the master with each reproduction by means of plug gages only.

Tool proofing after each dock operation is fast and convenient, and it will not interfere with the flow of tooling production. For example, with the setting of the last locator from an index template, the tool proofer needs only to plug into two holes; then the finished jig or fixture is completely inspected, ready to be put to use.

Strip templates can be used for rechecking purposes and for restoring original setups. Therefore, neither tool masters nor control masters are required as long as a master tooling dock is available. However, both tool masters and control masters can be constructed in the dock, if it becomes necessary to check or duplicate a jig or fixture in a subsidiary plant where no dock is available.

Contour Mastering

In almost every streamlined structure, there are a certain number of surfaces with compound contours—for example, the fenders of an automobile and the wing surfaces of an airplane. Of these, as previously explained, it is a common practice to make "mock-ups," or master contour models, whence various stretching and forming dies, trim fixtures, drill jigs, and other production tools can be produced. If production tools are made from a mock-up which is not precisely co-ordinate with the assembly tools that fix the contours of the more robust internal structure, they will fail to some degree in their purpose. It is simply a matter of "fitting the glove to the hand."

Previously, many factories have had to utilize mock-ups that were built upon flimsy bases and under shop conditions that precluded the employment of precision methods. Although the technique of making plaster models has progressed considerably in recent years, there are still only a comparatively few manufacturers who can say that they

have solved the problem of co-ordination between external contour and internal structure. But that is mainly because the master tooling dock has not, at this writing, been universally utilized.

Exceedingly accurate and co-ordinate contour models have been produced in the master tooling dock by the following method:

(1) A rough steel skeleton of the mock-up is moved into the dock and positioned the same as a rough jig or fixture frame.

(2) Contour templates are placed on the skeleton the same as locating elements are positioned on a jig or fixture.

(3) The structure is covered with reinforcing mesh and faired in with hard gypsum or a similar material.

Each template thus used should be cut to the mold line of the body, and its edges should be suitably beveled. The fairing of the mock-up may be accomplished outside of the dock; but, if the lines layout is complex, it is generally advisable to accomplish this work in the dock, using the

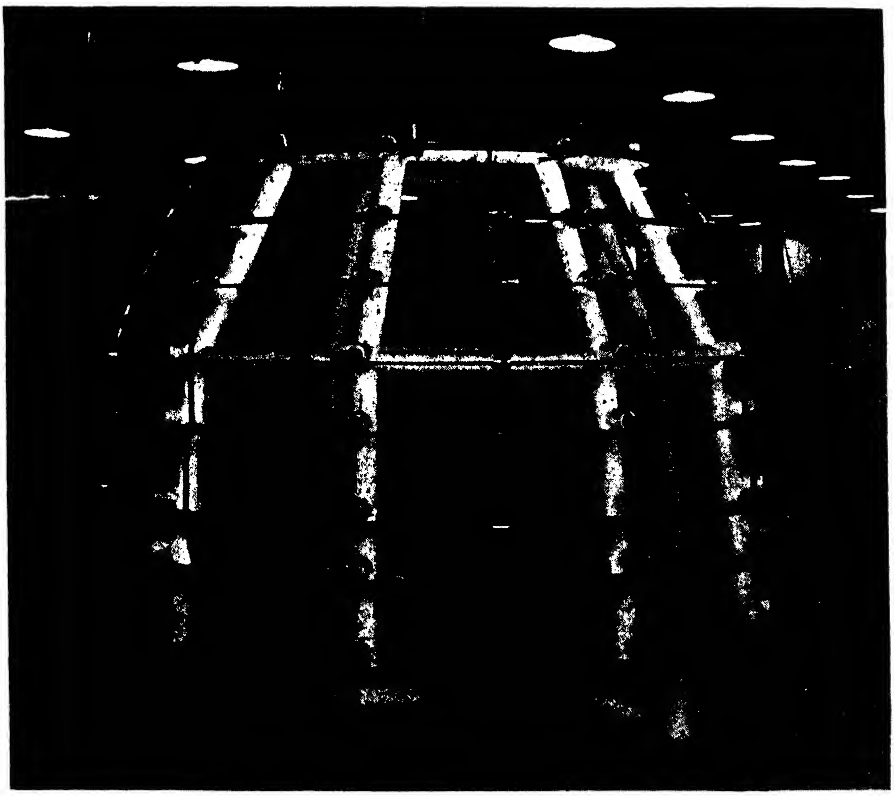


FIG. 94. Mock-up Skeleton with Contour Templates.

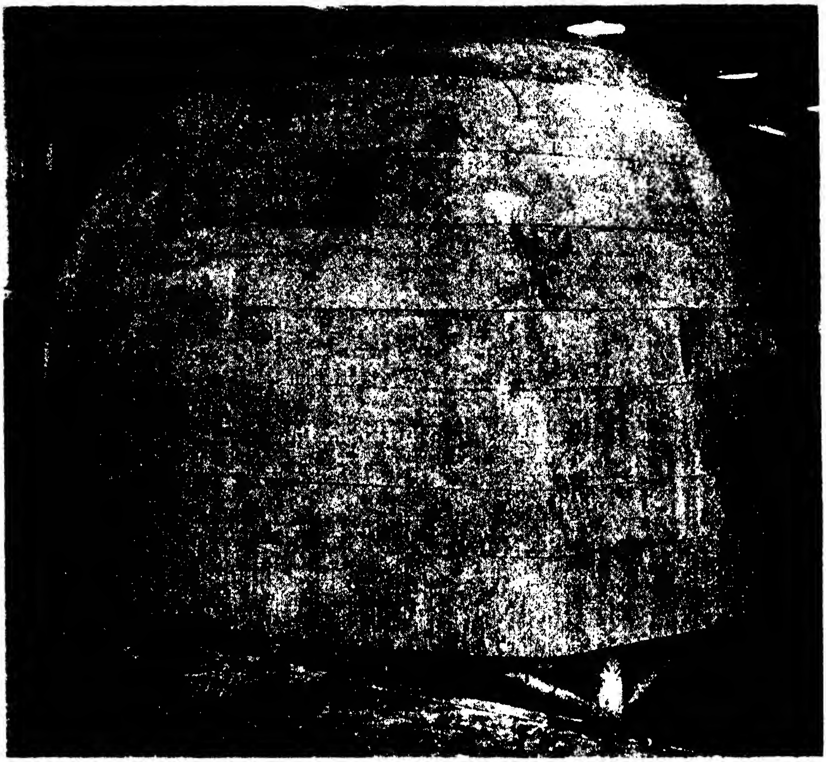


Fig. 95. Completed Mock-up.

straightedges thereof to guide the "mouse" during the scribing operations.

Fig. 94 shows an airplane nose mock-up skeleton with contour templates that were positioned in the master tooling dock. Fig. 95 shows the same mock-up after it has been covered with reinforcing mesh and faired in with hard gypsum.

Lines Scribing and Jig Boring

Although it was designed for three-dimensional positioning operations, the master tooling dock can also be used in connection with work that is essentially two-dimensional—for example, lines scribing and jig boring.

Lines scribing is important in factories where tooling docks are installed, because the grid lines which enable engineers to fair a streamlined body should be exactly the same as the grid lines established by the dock. It is accomplished simply by using the straightedges of the

dock to guide the scriber, which places grid lines on the various layout boards or plates.

The master tooling dock becomes analogous to a jig borer when its verticals are dispensed with, and a transverse straightedge is used to locate stations on the lower longitudinal straightedges. As indicated in Fig. 96, the second dimension is established by a fitting on the transverse straightedge. The work is supported in a horizontal position beneath the transverse straightedge, and the drilling or boring is accomplished by inserting the cutting unit of a table drill or boring head through a drill bushing in the second-dimensional fitting.

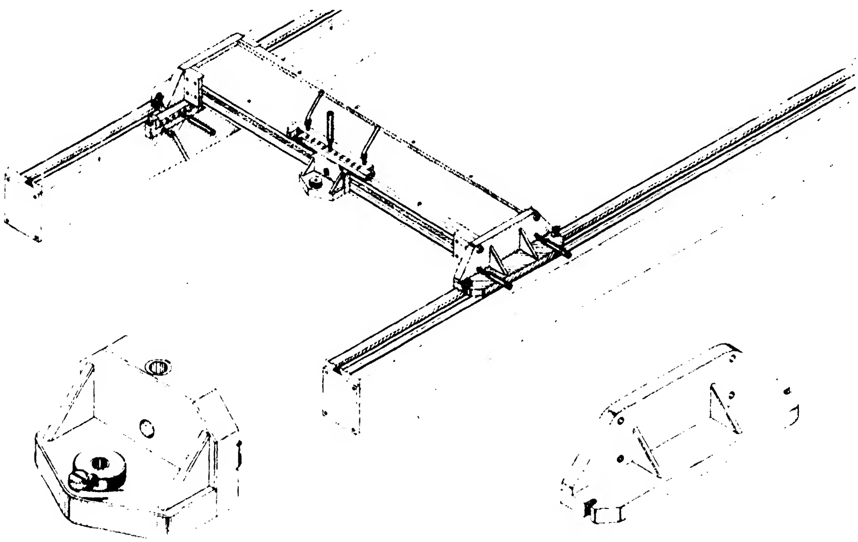


FIG. 96. Tooling Dock Equipped for Jig Boring.

As a jig borer, the master tooling dock is not as fast as the tools ordinarily utilized in mass production; but, in view of its universal applications, it is far less expensive—especially when employed in connection with temporary setups. It will also handle much larger layouts than will a conventional jig borer.

Designing Tools for the Master Tooling Dock

The three most important considerations in designing tools for master tooling dock setups are:

(1) The jig or fixture structure need not have machined surfaces from which the toolmaker may work in establishing the positions of his locators, because the locators are securely held in the dock clear of the

rough structure. The securing of the locator to the rough structure is simply a uniting operation, and the manner in which this is accomplished may be at the discretion of the tool designer.

(2) The tool designer should at all times remember that the dimensional controls which establish the positions of the locators on his tool are produced by master layouts and basic engineering dimensions; and that such arbitrary dimensions as he establishes on the tool should be primarily related to the tool structure, all other dimensions being merely noted for reference purposes. Also, the tool designer should call out the templates essential to the construction of his tool and note these on the tool-design drawing.

(3) The tool designer should show the essential framework of each assembly in phantom, and relate the axis of each tool structure to the basic reference lines, so that the structure may be correctly positioned in the master tooling dock during setup operations.

Further, it has been found advantageous to prepare with each tool design a sketch showing how each tool should be set up in the master tooling dock. On such a sketch, the correlation between the basic grid lines of the dock and the basic grid lines of the assembly should be developed.

It is optional with the tool designer as to whether he locates his components by nesting to contour blocks or by assembling on tool holes; either way, the tool hole serves to position the locator. If the components are nested to contour blocks, the tool hole acts simply as a construction hole during dock setup operations.

Use of the Master Tooling Dock

As explained in Chapter 2, the advent of the master tooling dock makes it possible to apply mass-production principles to the business of tool fabrication, because the flow of tools through a dock is akin to the flow of parts on a mechanized assembly line. Accordingly, the old method of assigning separate men to the responsibility of constructing given tools from start to finish has given way to the system of utilizing groups of specialists.

This practice in turn makes it possible to schedule the various processes of tool fabrication, so that an entire manufacturing program can be carried out with precise timing—thus reducing costs to a minimum. The co-ordination of tool-fabrication activities can be effectively administered by the production control group that orders materials, procures essential drawings, and does other related jobs.

In one large factory, over-all tooling efficiency has been so increased by a master tooling dock unit that the "loading plan board" shown in Fig. 97 can now be utilized. On this board the planned sequence of tools scheduled to go through the dock is shown to provide a visible reference for group leaders, enabling them to program the priority of their work with timely co-ordination.

The Tooling Ways

The *tooling ways* is a special version of the master tooling dock, designed to facilitate small-scale positioning operations on an economical basis. Its physical characteristics are indicated in Fig. 98.

Like the master tooling dock, the tooling ways reproduces or represents the lines of a grid plane system, so that points in space can be located in conformity with a master loft or body plan by positioning a series of straightedge members with proper relationship to one another. There are two fixed longitudinal straightedges to represent length dimensions or station lines; two vertical straightedges to represent height dimensions or water lines; and one transverse straightedge to represent width dimensions or buttock lines.

The longitudinal straightedges are held in a fixed horizontal position above the surface of the floor by means of a steel supporting structure, which is fastened to the floor with bolts, and micrometric adjusting screws make it possible to align these members in true parallel relationship. Each vertical straightedge comprises one side of an angle block, which may be moved to any desired position on either longitudinal straightedge. The transverse straightedge is an individual member, which may be positioned at any height on the vertical straightedges.

Except for the verticals, the straightedges of the tooling ways are exactly the same as the straightedges of a tooling dock. In point of fact, a tooling-ways installation can be readily made into a tooling dock, simply by placing a suitable foundation beneath its supporting structure and adding a superstructure which will make it possible to utilize the previously described vertical and upper longitudinal straightedges.

Because it is susceptible to deflection due to changes in the position of the floor, the tooling ways will not retain its fixed straightedge alignment so long as will a master tooling dock. However, it costs less than half as much as even a very small tooling dock. Although its dimensions are limited, it could be used to accomplish virtually all of the assembly tooling for streamlined structures such as those of light airplanes and automobiles. Fig. 99 compares the dimensions of a tooling-ways installation with the dimensions of a small helicopter.

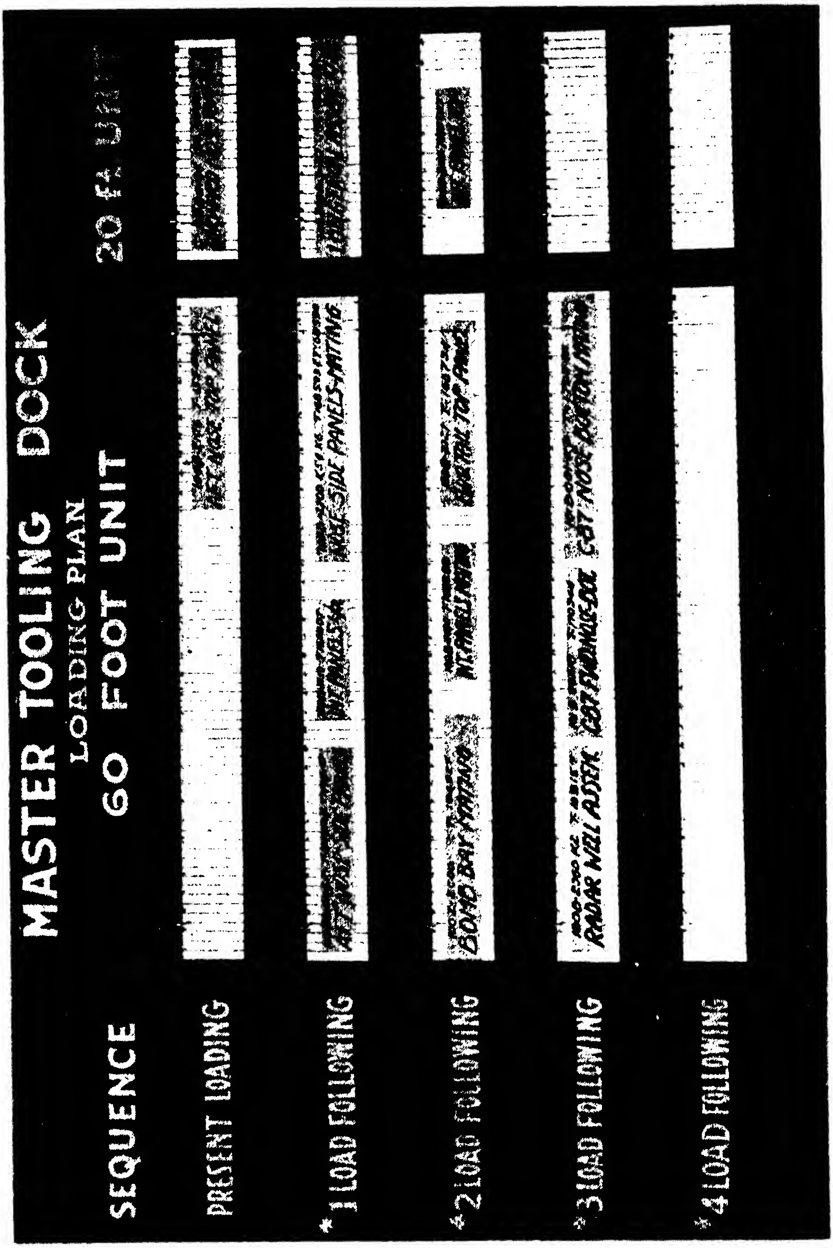


FIG. 97. Loading Plan Board.

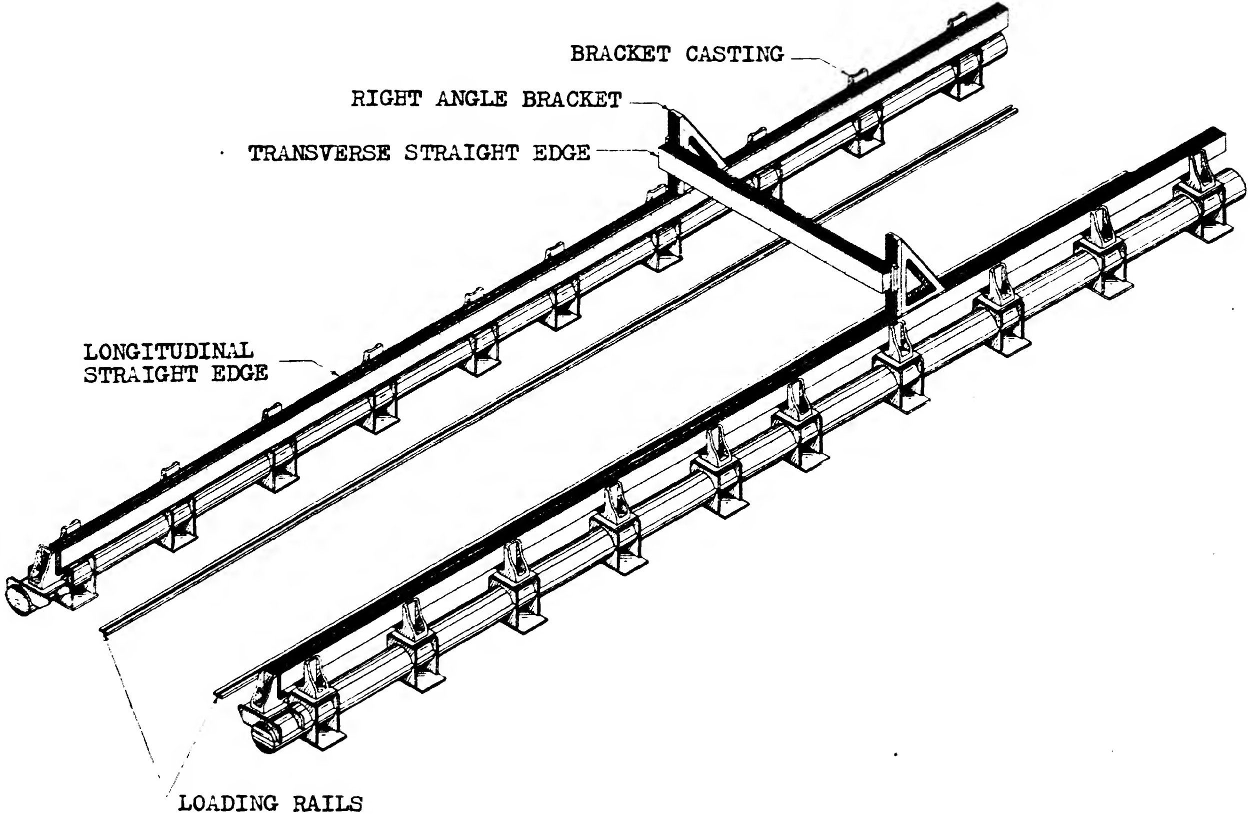


FIG. 98. Tooling Ways. (Approximate dimensions of tooling ways: maximum length, 60'; maximum height, 5' 11"; distance between longitudinal straightedges, 9' 1".)

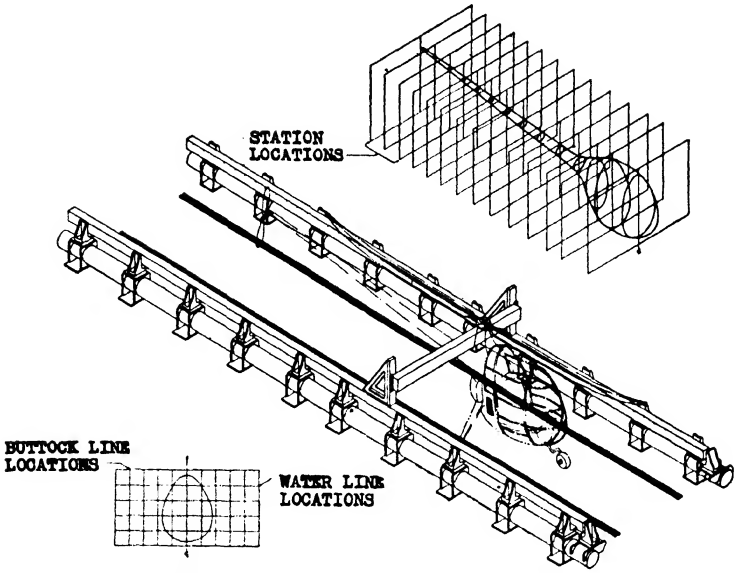


Fig. 99. Tooling Ways and Small Helicopter.

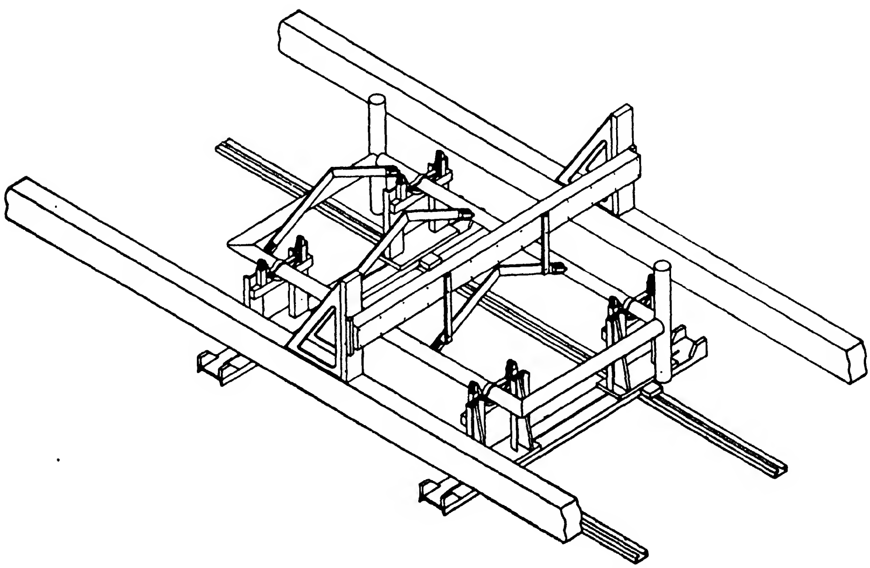


Fig. 100. Positioning Locators in Tooling Ways.

Both strip and index templates can be used in connection with the tooling ways. However, the latter are not preferable because the limited height of the vertical straightedges makes it impractical to utilize two transverse straightedges. Therefore, the best method for positioning jig or fixture locators in the tooling ways is that which necessitates the use of dummy fittings for the establishment of the third dimension. Fig. 100 shows how the locators for a picture-frame fixture may be thus positioned.

Because it is more essentially a two-dimensional structure, the tooling ways makes a better universal jig borer than a master tooling dock. It could also be used in constructing very small contour models.

CHAPTER 7

CONSTRUCTION OF JIGS AND FIXTURES

Materials

SINCE IT is cheap and easy to work with, wood was probably the first material to be used in constructing jigs and fixtures. However, wood is now considered unsuitable for most precision tooling purposes because its strength properties are inadequate and because it will not retain close dimensions in the presence of varying atmospheric conditions. Therefore, with but a few exceptions which will be discussed later, modern jigs and fixtures are made of metals.

The most frequently used metals are iron and steel, although lightweight metals such as aluminum and magnesium are preferable for many types of work.

Generally speaking, tooling metals should have the following physical characteristics:

(1) Good formability.
(2) Good strength properties.
(3) Ability to retain close dimensions.
(4) Resistance to handling impacts.
(5) Salvageability.

Iron and Steel

The basic commercial form of iron is known as *pig iron.* It is produced by removing undesirable elements from iron ore in a blast furnace, and contains about 93 per cent pure iron along with varying percentages of carbon, silicon, phosphorus, sulfur, and other elements. It is classified in accordance with the method by which it is manufactured, its intended use, or its composition. The methods of manufacture produce *coke pig iron,* which is smelted with coke and a hot blast; *charcoal pig iron,* which is smelted with charcoal and either a hot or a cold blast; and *anthracite pig iron,* which is smelted with anthracite coal mixed with coke and a hot blast. According to usage, it is *Bessemer pig iron,* if it is used for the Bessemer and acid open-hearth processes

of making steel; *basic pig iron,* if it is used in connection with a basic process; *malleable pig iron,* if it is used in making malleable cast-iron castings; *foundry pig iron,* if it is used for foundry work; and *forge pig iron,* if it is inferior stock which can be used for puddling and certain types of foundry work. The compositional classifications are in conformity with the varied chemical formulas for the material.

Iron which contains 1.7 to 6 per cent carbon is generally classified as *cast iron.* Since it is never more than a slightly refined version of pig iron it is very cheap, and for this reason is widely used in modern factories. It can be readily cast into numerous intricate shapes and machined to extremely close dimensions. However, because it is generally brittle and subject to breakage, it should never be used in fabricating jigs or fixtures which must withstand extensive handling. Table 1 lists the chemical composition and physical properties of some of the types of cast iron in common use.

Wrought iron is produced by refining pig iron in a puddling furnace. This iron is an excellent material for the fabrication of jig or fixture structural members, has tensile strengths in excess of 40,000 pounds per square inch, and is ideal for forging or welding. But it is not now generally used, because the mild forms of commercial steel have similar physical properties and are much less expensive.

The term *steel* is applied to many mixtures which differ from one another in chemical and physical properties, although the most important ingredients in each are carbon and iron. The general steel classifications are:

(1) *Bessemer steel* is made by blowing cold air under high pressure and in small streams through molten pig iron. This reduces the silicon, manganese, and carbon contents of the iron. The chemical reaction from oxygen in the air increases the temperature of the molten metal and forms the chief fuel as carbon is oxidized and eliminated.

TABLE 1. Average Physical Properties and Chemical Compositions of Cast Iron

Type of cast iron	Percentages of alloying elements (Asterisk indicates element is optional.)									Physical properties	
	C	Si	Mn	P	S	Ni	Cr	Mo	V	Maximum tensile strength (lb./sq. in.)	Modulus of elasticity (tension)
Soft	3.70	1.75	0.50	0.40	0.10	—	—	—	0.15*	16,000	12,000,000
Medium	2.25	1.85	0.50	0.35	0.10	—	—	—	—	22,000	16,000,000
Hard	3.0	1.25	0.60	0.20	0.10	2.75	0.80	—	—	35,000	20,000,000
High-test	2.75	2.25	0.65	0.15	0.10	0.75*	0.30*	0.50*	—	45,000	22,000,000
Malleable	1.5	0.9	0.3	0.2	0.10	—	—	—	—	54,000	25,000,000

Key: C, carbon; Si, silicon; Mn, manganese; P, phosphorus; S, sulfur; Ni, nickel; Cr, chromium; Mo, molybdenum; V, vanadium.

(2) *Crucible or tool steel* is made by refining iron scrap, blister steel, or wrought iron. The metal is melted in a graphite crucible, then alloying elements and suitable fluxes are added. This removes all undesirable elements and leaves a highly refined alloy which is cast into ingots.

(3) *Electric steel* is made in an electric furnace. It is a high-strength steel of extremely uniform quality.

(4) *Open-hearth steel* is made by melting pig iron, iron scrap, or steel scrap in a regenerative furnace. While the mixture is boiling, pure lump iron ore is added until the carbon is reduced to a low value.

The physical properties of a steel depend largely upon its alloying elements, most common of which are:

(1) *Carbon* is used in varying percentages to produce different results. Steels which contain less than 0.33 per cent carbon are easy to weld and difficult to harden, whereas steels which contain more than 0.75 per cent carbon are difficult to weld and easy to harden.

(2) *Chromium* is used to increase resistance to corrosion and heat.

(3) *Cobalt* is used to increase strength and corrosion resistance. Because it is rather expensive, cobalt is most generally used in making superhigh-speed or magnetic steels.

(4) *Copper* is used in small percentages to increase resistance to wear.

(5) *Lead* is used to improve machinability and to refine grain.

(6) *Manganese* is used as a "deoxidizing agent" to reduce brittleness caused by the presence of sulfur. Steels with more than 12 per cent manganese become nonmagnetic.

(7) *Molybdenum* is used to reduce brittleness and increase strength. It is frequently found in combinations of chromium, nickel, and vanadium.

(8) *Nickel* is used to increase resistance to corrosion and wear. In quantities of 1 to 5 per cent, nickel dissolves ferrite and strengthens steel by refining its grain.

(9) *Nitrogen* is used to promote ductility and refine the grain of high-chromium steels.

(10) *Phosphorus* is sometimes used with copper to increase the corrosion resistance of a steel. A high-phosphorus content will increase the fluidity of molten steel, but causes the hardened metal to become excessively brittle.

(11) *Silicon* is used in amounts of 0.75 to 2.5 per cent to increase strength. More than 2.5 per cent silicon enhances the corrosion resistance of a steel, but causes extreme brittleness. Less than 0.75 per cent silicon is considered an impurity.

(12) *Sulfur* may be used in quantities of not more than 0.25 per cent to increase machinability. Larger percentages are never desirable.

(13) *Titanium and columbium* are used to prevent air hardening in intermediate steels which contain chromium.

(14) *Tungsten* is used to increase the hardness and strength of high-speed steels.

(15) *Vanadium* is used in small percentages with other alloying elements to refine grain and increase toughness.

The Society of Automotive Engineers has probably the most practical group of specifications for general-purpose steels, and a numerical-index system makes it possible to identify the specified metals on shop drawings. The first figure in the system denotes the class to which the steel belongs; the second figure usually indicates the approximate per cent of the predominant alloying element; and the last two or three numerals indicate the average carbon content in "points," or hundredths of one per cent. The basic numerals have the following significance:

Type of Steel	*Numerals*
Carbon steels:	
Plain carbon	10XX
Free cutting (screw stock)	11XX
Manganese steels	13XX
Nickel steels:	
3.50% nickel	23XX
5.00% nickel	25XX
Nickel-chromium steels:	
1.25% ni, 0.60% cr.	31XX
1.75% ni, 1.00% cr.	32XX
3.50% ni, 1.50% cr.	33XX
Corrosion- and heat-resistant	30XX
Molybdenum steels:	
Carbon molybdenum	40XX
Chromium molybdenum	41XX
Chromium-nickel-molybdenum	43XX
Nickel molybdenum, 1.75% ni.	46XX
Nickel molybdenum, 3.50% ni.	48XX
Chromium steels:	
Low chromium	51XX
Medium chromium	52XXX
Corrosion- and heat-resistant	51XXX
Chromium-vanadium steels (1% chromium)	61XX
Silicon-manganese steels (2% silicon)	92XX

Accordingly, "2340" denotes a nickel steel containing approximately 3 per cent nickel and 0.40 per cent carbon. It has occasionally been

found necessary to vary this system in order to avoid confusion, but to date the variations have been confined largely to the corrosion- and heat-resistant steel numerals, as indicated above.

The type of iron or steel used in constructing a jig or fixture depends primarily upon such considerations as costs, methods to be used in fabricating or assembling the tool, and the loads which the finished structure will be required to support. From a strict cost standpoint, a cast-iron structure may seem to be preferable, but when fabrication and production problems are taken into consideration, wrought-iron and low-carbon steels are often found to be best.

Table 2 compares the average strengths of the most commonly used types of iron and steel.

Aluminum and Magnesium

The weight of a jig or fixture becomes an important item when it is found that the time and effort involved in handling the tool may seriously affect the cost of a fabrication or assembly operation. Whenever a low-weight structure is required, aluminum and magnesium alloys may be advantageously used, even though the initial cost of either is normally higher than the initial costs of iron and steel. This can be readily understood when it is realized that aluminum and magnesium have respective weights of only 159.7 and 108.6 pounds per cubic foot, whereas cast iron and steel have respective weights of 449.2 and 486.7 pounds per cubic foot.

In its pure form, aluminum is a very soft and malleable metal of low strength and very little practical value; when alloyed with other materials, however, it can remain light and yet develop strengths which make it comparable to certain types of steel. The most common aluminum-alloying elements are copper, magnesium, silicon, chromium, zinc, iron, and manganese. As a rule, two or more of these elements are found in each aluminum alloy.

The most widely used method of designating aluminum alloys is to assign a number to the chemical composition and then add letters to denote the different conditions in which the alloy is used. Table 3 gives the symbol numbers and compositions of commercial aluminum alloys produced by the Aluminum Company of America (ALCOA). Letters that may also be used in connection with these symbol numbers have the following significance:

S—a wrought product. This includes all forms except castings (as 56S, a soft wrought alloy, not heat treated).

O—fully annealed, the softest condition.

TABLE 2. Average Strengths of Iron and Steel Materials

Material	Ultimate strength in pounds per square inch			Yield point in pounds per square inch	Modulus of elasticity in tension	Elongation in two inches (per cent)
	Tension	Compression	Shear			
Soft cast iron	16,000	80,000	17,000	—	12,000,000	—
Medium cast iron	22,000	100,000	24,000	—	16,000,000	—
Hard cast iron[a]	35,000	150,000	38,000	—	20,000,000	—
High-test cast iron[b]	45,000	200,000	50,000	—	—	—
Malleable casting	54,000	—	48,000	36,000	25,000,000	18
Steel casting[c]	70,000	70,000	60,000	40,000	30,000,000	25
Carbon steel[d]	56,000	56,000	42,000	28,000	29,000,000	30
Cold-worked[e]	75,000	75,000	55,000	38,000	30,000,000	—
Casehardened[f]	80,000	80,000	60,000	50,000	30,000,000	20
Hard-drawn[g]	120,000	120,000	90,000	90,000	30,000,000	15
Machinery steel[h]	60,000	60,000	45,000	40,000	30,000,000	—
Nickel steel[i]	130,000	130,000	98,000	100,000	30,000,000	18
SAE 2330	145,000	145,000	110,000	120,000	30,000,000	18
SAE 2340	165,000	165,000	125,000	150,000	30,000,000	12
Nickel-chromium[j]	125,000	125,000	95,000	95,000	30,000,000	18
SAE 3130	150,000	150,000	110,000	125,000	30,000,000	15
SAE 3140	175,000	175,000	130,000	150,000	30,000,000	—
SAE 3230	180,000	180,000	135,000	150,000	30,000,000	15
SAE 3240	200,000	200,000	150,000	180,000	30,000,000	15
SAE 3250	220,000	220,000	165,000	200,000	30,000,000	12
Rivet steel	57,000	57,000	44,000	36,000	29,000 000	—
Stainless steel[k]	225,000	225,000	—	185,000	—	9
Structural steel	60,000	60,000	45,000	30,000	29,000,000	22
Wrought iron	48,000	46,000	40,000	25,000	27,000,000	—

[a] Compressive strengths of "white" and "high-test" irons may range from 175,000 to 250,000 pounds per square inch.

[b] Tensile strengths of "high-test" irons may range from 40,000 to 70,000 pounds per square inch; sometimes even higher.

[c] Heat-treated alloy steel castings may have tensile strengths of as much as 200,000 pounds per square inch.

[d] This is soft, open-hearth, annealed steel.

[e] The yield point may range up to 60,000 pounds per square inch, according to the amount of cold-working.

[f] These data are for SAE 1020 steel, casehardened and water-quenched and drawn to 400°F.

[g] This is SAE 1045 steel, hardened in water and drawn to 800°F.

[h] Some "machinery" steels have tensile strengths of as much as 100,000 pounds per square inch.

[i] This is SAE 2320 steel. The strength data for all of the nickel steels listed are based upon a drawing temperature of 800°F. and oil-quenching.

[j] This is SAE 3120 steel. The nickel-chromium steels listed are drawn to 800°F.

[k] The strength data here are for a stainless steel drawn to 390°F.

TABLE 3. Commercial Aluminum Alloys

	Type*	Alcoa alloy	Composition (%)				
			Cu	Fe or Mn	Si	Mg	Other
Nonheat-treated casting alloys	I	173	7.0	—	—	—	2.0 Sn
		C113	7.5	1.2 Fe	4.0	—	2.0 Zn
		645	2.5	1.5 Fe	—	—	11.0 Zn
		B113	7.5	1.2 Fe	1.5	—	—
	II	112	7.5	1.2 Fe	—	—	2.0 Zn
		216	—	—	—	6.0	—
		A214	—	—	—	3.8	2.0 Zn
		109	12.0	—	—	—	—
		12	8.0	—	—	—	—
		214	—	—	—	3.8	—
		212	8.0	1.0 Fe	1.2	—	—
		B214	—	—	1.8	3.8	—
	III	172	7.8	—	2.5	—	—
		A108	4.5	—	5.5	—	—
		108	4.0	—	3.0	—	—
		356	—	—	7.0	0.3	—
		43	—	—	5.0	—	—
Heat-treated casting alloys[a]	I	220[b]	—	—	—	10.0	—
		122	10.0	1.2 Fe	—	0.2	—
	II	D195	5.5	—	0.7	—	—
		142	4.0	—	—	1.5	2.0 Ni
		195	4.0	—	—	—	—
		B195	4.5	—	3.0	—	—
	III	355	1.3	—	5.0	0.5	—
		A355	1.4	0.8 Mn	5.0	0.5	0.8 Ni
		356	—	—	7.0	0.3	—
	c	A132	0.8	0.8 Fe	12.0	1.0	2.5 Ni
Heat-treated wrought alloys[a]	I	11S	5.5	—	—	—	0.5 Pb + 0.5 Bi
	II	61S	0.25	—	0.6	1.0	0.25 Cr
		53S	—	—	0.7	1.3	0.25 Cr
		A51S	—	—	1.0	0.6	0.25 Cr
		17S	4.0	0.5 Mn	—	0.5	—
	III	25S	4.5	0.8 Mn	0.8	—	—
		70S	1.0	0.7 Mn	—	0.4	10.0 Zn
		18S	4.0	—	—	0.5	2.0 Ni
		14S	4.4	0.8 Mn	0.8	0.4	—
		24S	4.4	0.5 Mn	—	1.5	—
	c	32S	0.8	—	12.0	1.0	0.8 Ni
Nonheat-treated wrought alloys	II	56S	—	0.1 Mn	—	5.2	0.1 Cr
	III	4S	—	1.2 Mn	—	1.0	—
		52S	—	—	—	2.5	0.25 Cr
		3S	—	1.2 Mn	—	—	—

Key: Cu, copper; Fe, iron; Mn, manganese; Si, silicon; Mg, magnesium; Sn, tin; Zn, zinc; Ni, nickel; Pb, lead; Bi, bismuth; Cr, chromium.

* Indicates relative machinability. Type I alloys have best machining characteristics.

[a] Heat-treated as usually sold: namely, a solution treatment followed by aging at room or elevated temperature.

[b] Alloy 220 is not aged.

[c] Alloy cuts freely, but wear on tools may be excessive unless they are tipped with cemented carbide.

H—fully work-hardened, usually accomplished by rolling or bending. The symbols ¼H, ½H, and so forth designate conditions of relative hardness caused by limited work-hardening.

W—a condition caused by quenching after heat treatment, but before age hardening.

T—a fully heat-treated condition, produced by aging after quenching.

RT—an extremely hard condition, caused by heat treating, aging, and cold rolling.

Aluminum alloys are available in the form of rods, bars, sheet, tubing, foil, rivets, wire, forgings, billets and extrusions. Considerable care must be exercised in welding these materials because they will melt without changing color as does iron or steel; but they can be cast or formed by virtually all common shop methods without great difficulty. Their tensile strengths range to more than 87,000 pounds per square inch.

As an element, magnesium is considerably stronger and lighter than aluminum; but since it is not naturally fire and corrosion resistant, it is used also as an alloy. The most common magnesium-alloying elements

TABLE 4. Commercial Magnesium Alloys

Dow symbols	Composition (%)					
	Al	Mn	Cd	Zn	Cu	Si
A	8.0	0.15	—	—	—	—
B	12.0	0.10	—	—	—	—
F	4.0	0.20	—	—	—	—
G	10.0	0.10	—	—	—	—
H	6.0	0.15	—	3.0	—	—
J	6.9	0.15	—	0.7	—	—
K	10.0	0.10	—	—	—	0.75
M	—	1.50	—	—	—	—
O	8.5	0.15	—	0.5	—	—
E	6.0	0.30	—	—	—	—
L	2.5	0.20	—	—	—	—
P	10.0	0.10	—	2.0	—	—
T	2.0	0.20	2.0	—	4.0	—
X	3.0	0.20	—	3.0	—	—
EX	6.5	0.20	—	—	—	0.20
R	9.0	0.13	—	0.6	—	—

Key: Al, aluminum; Mn, manganese; Cd, cadmium; Zn, zinc; Cu, copper; Si, silicon.

are aluminum, manganese, cadmium, zinc, copper, and silicon. Table 4 gives the compositions of commercial magnesium alloys manufactured by The Dow Chemical Company.

Magnesium alloys are available in the form of rods, extrusions, sheet, castings, and forgings. Some of these have a tendency to burn when subjected to high temperatures, while others will crack when cold-formed; but, generally speaking, they can be fabricated by machining, forming, welding, cutting, or casting. Their tensile strengths range to more than 35,000 pounds per square inch.

Light-weight-metal jigs or fixtures are particularly desirable when it is necessary to machine bulky objects, such as automobile crankcases and cylinder blocks, where extreme weight would make it difficult to load or unload the tools with maximum speed and efficiency. However, the following precautions should be observed in designing and fabricating such tools:

(1) If steel parts (such as inserts and bushings) must be used in contact with the light-metal parts of the tool, the dissimilar metals should be insulated to prevent corrosion. The insulation can usually be accomplished simply by dipping the steel part in zinc chromate immediately prior to making the necessary installation.

(2) If the tool must withstand considerable handling, its corners and edges should be suitably reinforced to prevent chipping or breakage. Iron or steel parts may be used as reinforcing members.

Methods of Construction

Not many years ago, a large percentage of metal jig and fixture structures were fabricated by casting; and this method may still be used advantageously when it is necessary to reproduce accurate contours (for example, as in making certain types of locating fixtures) or to make numerous replicas of any given tool structure. But owing to comparatively recent developments with welding, most tool engineers now prefer *built-up* structures.

A built-up structure can be generally defined as any physical unit which is made by assembling two or more members. It cannot be constructed with the accuracy of a cast structure; but since it does not necessitate the preliminary fabrication of a model and a mold, it can be manufactured with far greater speed and economy.

The basic structure of the average jig or fixture does not have to be extremely accurate, because its only function is to provide a rigid support for a series of locating elements. The accuracy of the locating elements may be attained by machining given surfaces or members of the structure.

Built-up structures normally comprise standard sections of material —such as round oil-well casing, pipe, round and square steel tubing, square and rectangular box sections, and structural steel shapes. Some of these are shown in Fig. 101. If they are properly analyzed and stressed, most built-up structures can be constructed from any one of several types of sections, cost and availability being the main considerations.

Because it is extremely economical, arc welding is the preferred method of uniting the members of an iron or steel structure. Gas welding is generally used in building up aluminum and magnesium structures because it can be most easily applied where low melting temperatures are required.

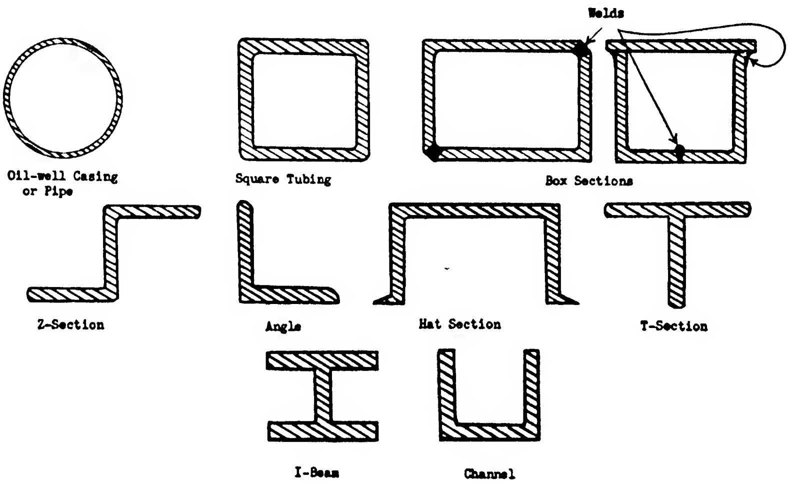


FIG. 101. Standard Sections of Materials.

Welding Problems

Welding presents a number of specialized manufacturing problems. If these problems are taken into consideration from the start, no particular difficulties should be encountered.

First of all, the tool designer should make sure that his intentions will not be misunderstood in the shop. To avoid any misinterpretation, he may find it necessary to prepare a special sketch showing precisely how the welding is to be done. Besides listing the sizes of material to be used, this sketch should indicate the amount or size of each welding fillet or bead.

The parts required to construct the desired jig or fixture may be cut

from stock sections with a saw or an oxyacetylene cutting torch, whichever is most convenient, and all necessary holes should be made in the parts prior to assembly.

When the parts are ready for welding, they may be appropriately assembled with clamps. Then the assembly should be securely tack-welded, so that the clamps can be removed and a finished job of welding can be accomplished.

As a rule, the cutting or welding of metal parts will cause strains in the members of a structure. If these strains are well distributed and cause little deformation, they may be ignored. Slight deformations can ordinarily be eliminated by machining the ends of the members or by peening the welding beads with a roundnose set in a rivet gun. In all cases, strains can be removed by annealing or normalizing the jig or fixture structure.

Iron or steel structures should be sandblasted after welding or annealing, so that loose particles or scale will be removed and the metal surfaces will be ready for painting. Aluminum and magnesium structures are prepared for painting by cleaning with a wire brush and anodizing.

Frequently it is a good idea to spray-paint a jig or fixture structure immediately after welding and annealing, even though certain parts of the tool may still require machining. The object of this is to prevent corrosion. If machining is required after the initial painting, a second coat of paint should be applied before the tool is put into use.

Welded jigs or fixtures are not always as easy to salvage as cast-tool structures, but they can be more readily altered to conform with varying engineering requirements. For example, changes can be made on the ends of clamps by welding on or cutting off certain pieces—thus eliminating the time-consuming milling operations that would be required in making similar changes in cast structures.

Measuring and Checking

Where the previously described master tools are not utilized, built-up jig or fixture structures may be measured and checked by the following methods:

(1) Direct measurements.
(2) Use of a surveyor's transit or level.
(3) Use of an alignment telescope and collimator.

Direct measurements are made by means of instruments such as rules, micrometers, height gages, and protractors. Where tolerances are large, such instruments may be entirely adequate for the dimensioning

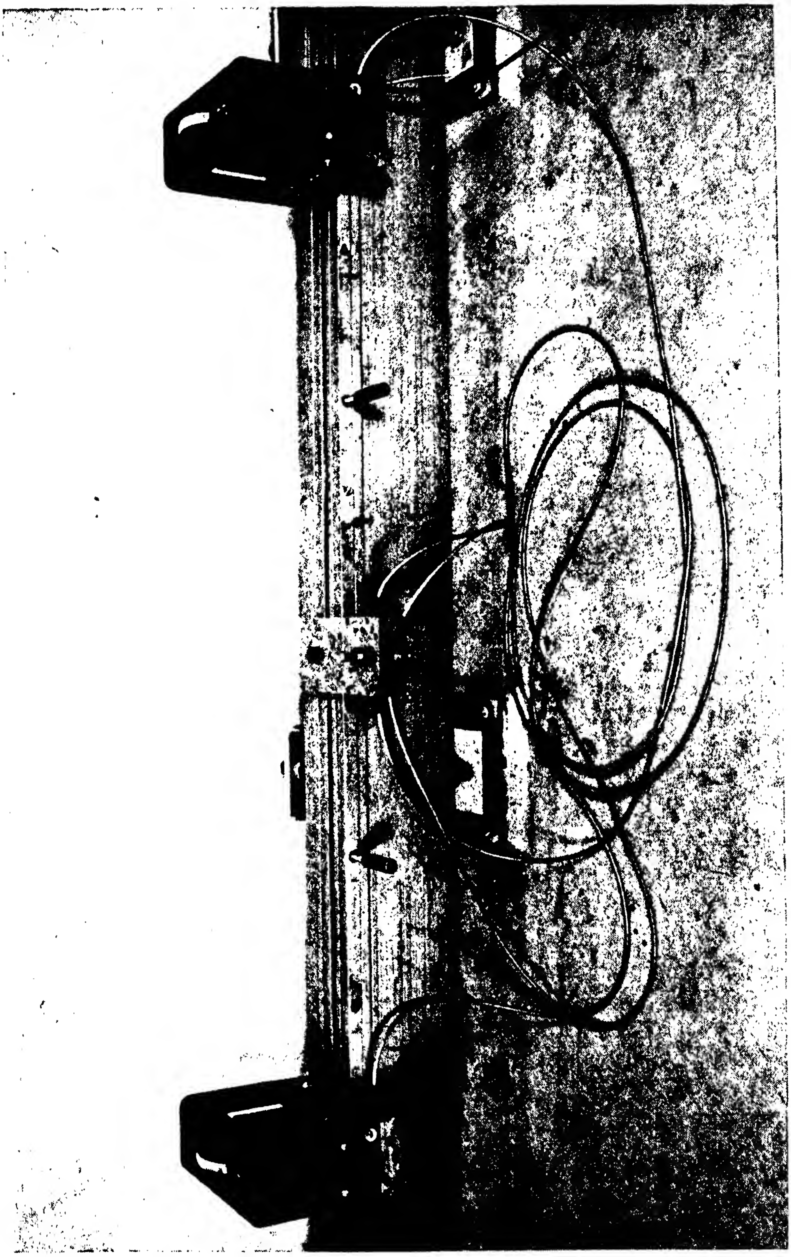


FIG. 102. Electronic Leveling Apparatus.

FIG. 103. Surveyor's Transit.

and checking of a jig or fixture structure; but when small tolerances are required, they are at best slow and tedious.

Electrical instruments produce the most accurate direct measurements. For example, the electronic leveling apparatus shown in Fig. 102 has been used to level the longitudinal straightedges of a master tooling dock to a tolerance of ±0.001 inch. However, equipment of this type is suitable for checking only one dimension at a time.

Surveyors' transits or levels, such as the instrument shown in Fig. 103, have been frequently used in aligning strands of piano wire (much the same as the straightedges of a master tooling dock are aligned) in order to establish three-dimensional locations for assembly jigs or fixtures.

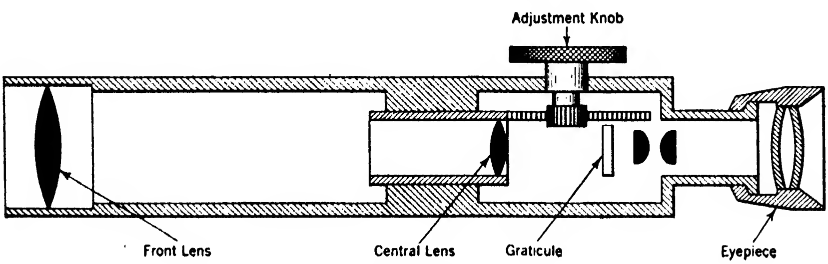


FIG. 104. Telescope.

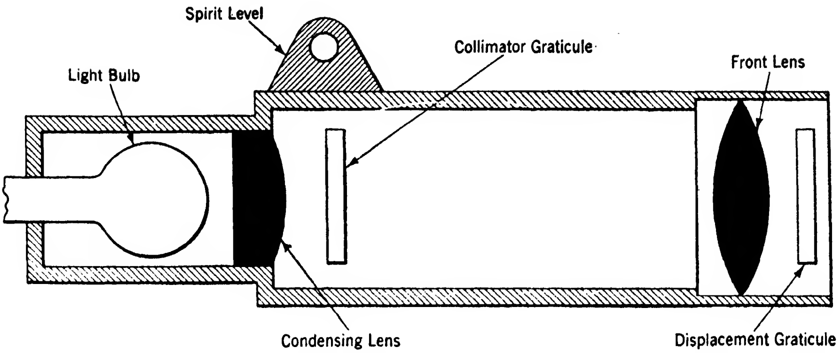


FIG. 105. Collimator.

But this method is slow and suitable only for the dimensioning of tools which do not have to produce interchangeable parts, because the thickness of the piano wire alone necessitates a considerable tolerance—even at close ranges, where the human eye can be relied upon to align the cross hairs of the transit telescope properly.

The fastest and most accurate optical method of setting up or checking assembly jigs or fixtures is the telescope-and-collimator system,

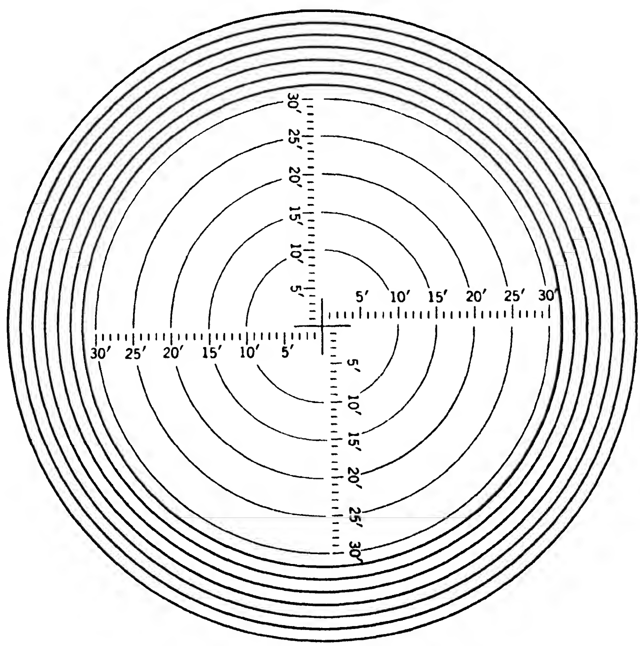


FIG. 106. Collimator Graticule.

which was developed in England. The object of the method is to establish an optical datum line by mounting the telescope and collimator on gaging pieces at opposite ends or sides of a jig or fixture.

As shown in Fig. 104, the telescope essentially comprises an ordinary lens system enclosed by a steel tube which is substantially made and hardened so that it may be clamped safely in suitable supports without marring, distortion, or misalignment. It also has a graticule, which is simply a pair of cross hairs on glass with their point of intersection centered on the axis of the telescope. Focusing the telescope is accomplished by moving the central lens by means of a knob on the outside portion of the tube. When the knob is rotated clockwise to its stop, the telescope is focused on infinity and may be thus used for measuring angular displacement. The eyepiece is adjustable to suit the sight of the user in focusing on the cross hairs of the telescope.

The collimator, as indicated in Fig. 105, has a small electric-light bulb mounted in its afterend. In front of this is a condensing lens and a collimator graticule, as illustrated in Fig. 106. The collimator graticule is situated in the focal plane of the front lens, so that light will leave the lens in a parallel beam. At this point, the light is "collimated" and the collimator graticule is at infinity as far as focusing by the telescope is concerned. The scales on the collimator graticule measure tilt in seconds and minutes of arc, and each small division represents a tilt of 30 seconds of arc (although accurate estimations can be made to one fifth of a division, or six seconds). The maximum measurable tilt is 30 minutes, but an image can be picked up at an inclination of two degrees. Lateral displacement is measured by the displacement graticule in front of the foremost lens; and, as indicated in Fig. 107, this graticule has double cross hairs at its center and six scales surrounding the cross hairs. The latter scales are of varying fineness, the smallest divisions representing 0.01 inch, and they may be used in making readings that are accurate within 0.005 inch in a distance of 20 feet (or 0.02 inch in 80 feet).

The collimator and the telescope are mounted opposite one another on gaging pieces, or "optical references" (as they are known), so that the instruments will be correctly related. The designs of the optical references vary in accordance with the nature of the unit upon which each is mounted, but all of them must be so extremely accurate that (during manufacture) their final adjustments are made in a temperature-controlled room. For example, the brackets which carry the telescope and collimator have a maximum allowable misalignment of 0.0005 inch in a length of two feet.

When it has been properly mounted (so that the first dimension in space is established), the collimator is adjusted so that its cross hairs

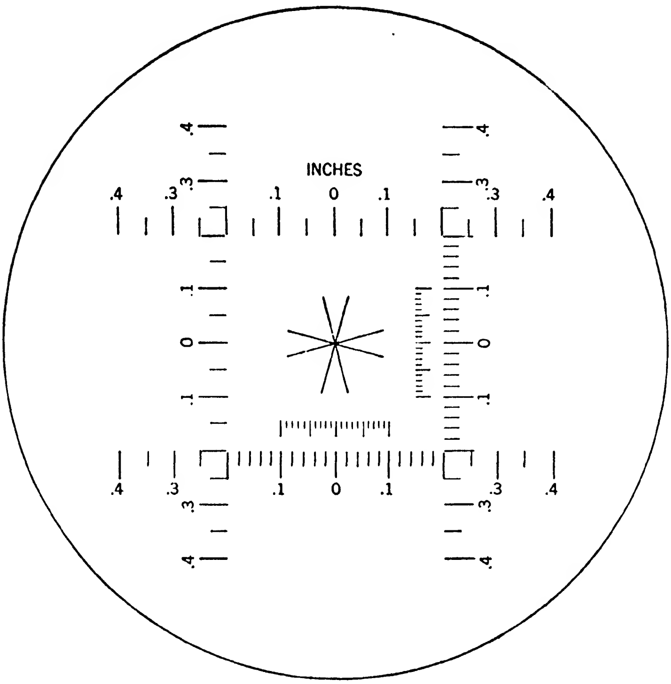


FIG. 107. Displacement Graticule.

will be perfectly horizontal and vertical by means of its external spirit level; then the telescope eyepiece is focused on the cross hairs of the telescope and the second instrument is set at infinity to focus on the collimator graticule. If the angular displacement is not too great for measurement, an image of the collimator graticule will appear so that the degree of tilt can be determined. The telescope can then be adjusted and focused so that lateral displacement can be read on the displacement graticule.

The image shown in Fig. 108 is formed at an angle with the horizontal when the telescope is focused on the collimator graticule. Therefore,

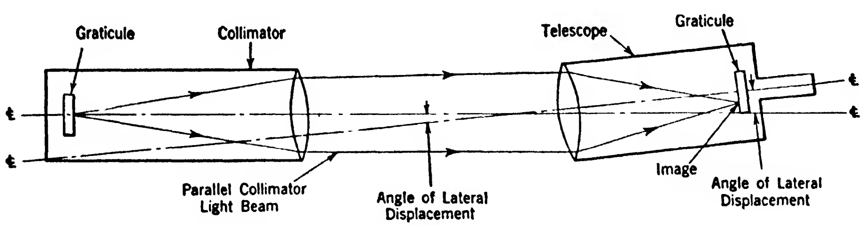


FIG. 108. Schematic "Tilt" Diagram.

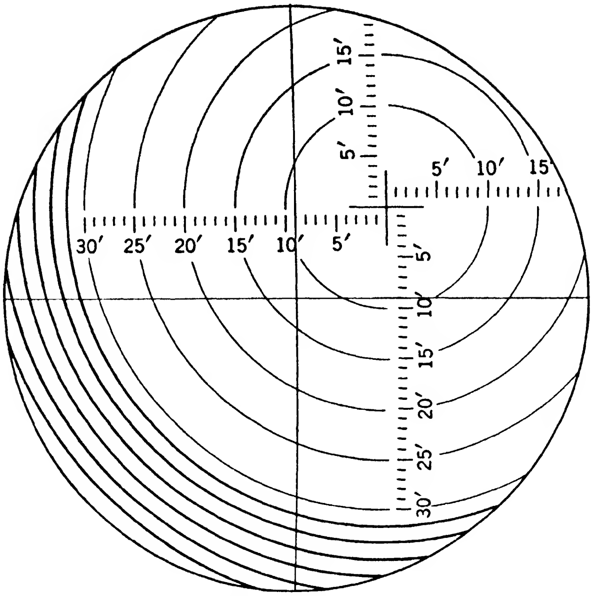


FIG. 109. Observed "Tilt."

it is projected from the graticule to an off-center position within the telescope, giving a tilt measurement. Fig. 109 shows how the tilt appears from the eyepiece of the telescope. In this particular example, the tilt amounts to nine minutes in each direction; and in all cases it is proportional to the angle shown between the instruments in Fig. 108. It is independent of the lateral displacement between the axes; but the tilt reading cannot be obtained if the lateral displacement is so great that the beam of light from the collimator fails to enter the telescope.

When the telescope is focused on the displacement graticule of the collimator, the extended optical axis of the telescope usually strikes the graticule at another off-center point, as indicated in Fig. 110. Accordingly, displacement may be directly read through the telescope. Fig. 111

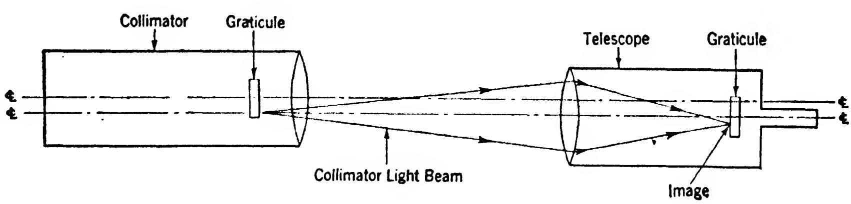


FIG. 110. Schematic "Displacement" Diagram.

shows how the displacement would appear if it were 0.18 inch horizontally and 0.175 inch vertically.

After the displacement adjustments have been made to the telescope, the second dimension in space is established and a *sighting target* should be used in place of the collimator so that intermediate points or third-dimensional locations can be established.

Fig. 112 shows a sighting target which has been of particular value in setting up assembly jigs or fixtures. It is a simple cursor or runner

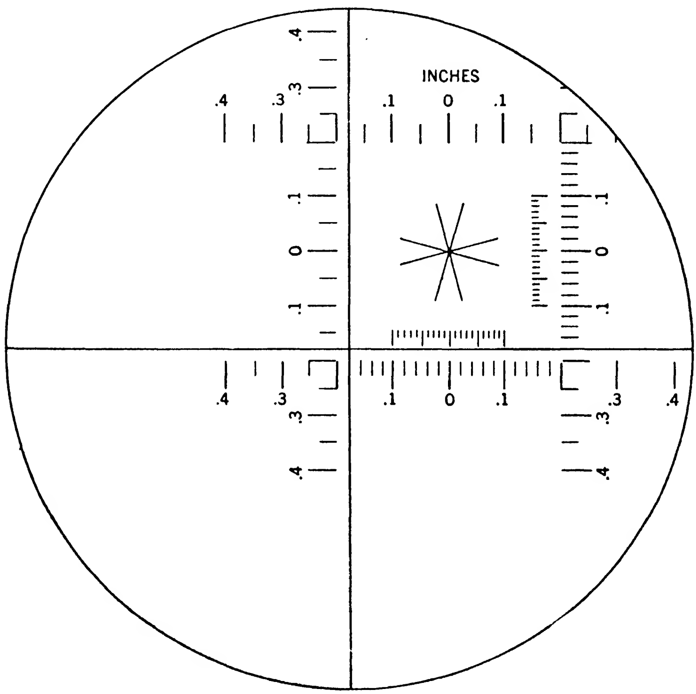


FIG. 111. Observed "Displacement."

mechanism with a vernier gage, and it is attached to a standard metal scale which is graduated in 0.020-inch divisions. Since the vernier is in 20 divisions, the consequent readings are accurate to 0.001 inch. A hairline is scribed exactly across the center of the plate on both the face and the back, and point 0 on the vernier scale is aligned with this scribe line.

Because it can be set up at intermediate points and can be accurately aligned, the leveling target can establish third-dimensional locations the same as a master tooling dock. However, since both instruments are

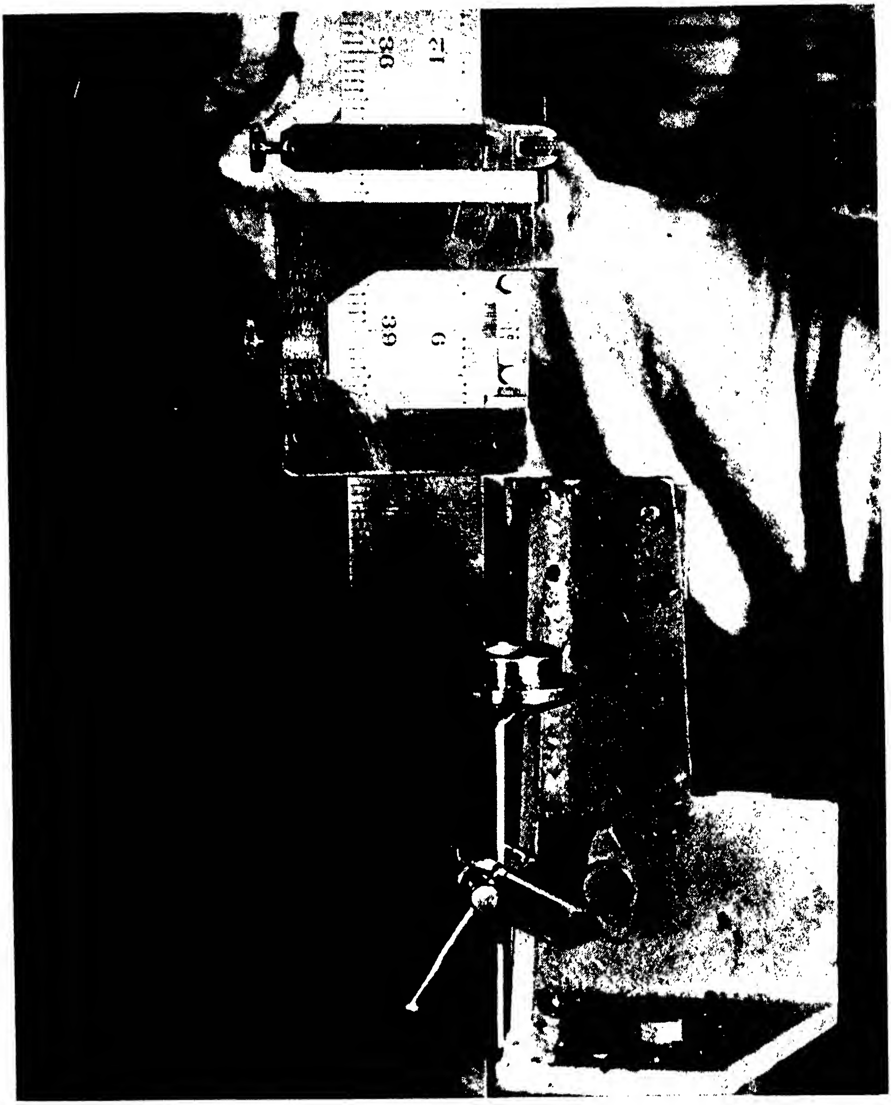


FIG. 112. Sighting Target.

dependent upon manual adjustments and optical alignment, the points thus established cannot be duplicated with extreme precision unless they are used in constructing masters.

All telescope-and-collimator measurements should be made in still air, because drafts or convection currents will cause unsteady images and impair the accuracy of the readings.

Component Gages

When a large number of jig or fixture parts with identical contours or dimensions are required, it is sometimes desirable to fabricate and utilize *component gages*. These are essentially the same as tool masters, except for the fact that they cannot be used to check an entire tool.

Before the jig or fixture is constructed, component gages can be used to determine whether parts of the tool have been properly fabricated. Then, after the parts have been assembled, they can be used to find out whether damage has been caused by handling.

Reference Points

If the accuracy of a jig or fixture is dependent upon the locations of key reference points, suitable reference lines may be scribed on the tool structure to facilitate checking. Masking tape can be used to protect the lines when they are not needed for checking purposes.

Another method of establishing reference points is to locate a leveling pad near each tool support. If all of the pads are machined to the same height, the jig or fixture can then be checked simply by placing a target on each pad in succession and leveling with a transit.

CHAPTER 8

PNEUMATIC AND HYDRAULIC MECHANISMS

Pneumatic Mechanisms

PNEUMATIC MECHANISMS make it possible to power jigs and fixtures with compressed air. Where mass-production requirements make pneumatic mechanisms economically desirable, they sometimes have many advantages over units which must be manipulated manually. For example, when used in connection with trunnion and indexing mechanisms, they may enable workmen to move tool members whose size or weight would make manual rotation difficult if not impossible. Further, when incorporated in holding or clamping mechanisms, they minimize general handling time by enabling operators to locate, clamp, and eject work merely by moving valve levers.

Some of the simpler pneumatic mechanisms are only slightly more expensive than the screws, clamps, and eccentrics which would ordinarily hold work in a jig or fixture. As a rule, the costs of handling must be balanced against the costs of tools in order to determine whether such mechanisms should be used. For example, if it is found that a pneumatic fixture will enable a worker to increase his output by 10 per cent in the course of a year, the more expensive tool may be a profitable investment; but if the fixture is to be used for only a few weeks, it is possible that even slightly excessive tool costs will not be offset by savings in handling time.

Because there are several factories which specialize in the manufacture of air-driven equipment, it is generally neither economical nor necessary for other plants to produce their own pneumatic mechanisms. However, every good tooling man should understand the principles as well as the applications of such equipment.

THE AIR CYLINDER

The air cylinder might be called the heart of a pneumatic mechanism, because it is the unit which actually derives mechanical power from the

pressure of compressed air. Essentially, it comprises a piston and a suitable housing therefor; and it is actuated when compressed air is injected into the housing, to alter the position of the piston.

Fig. 113 shows the cross section of a fairly simple compressed-air cylinder which has been used in connection with a wide variety of jigs and fixtures. It can be easily manufactured at a very low cost. The

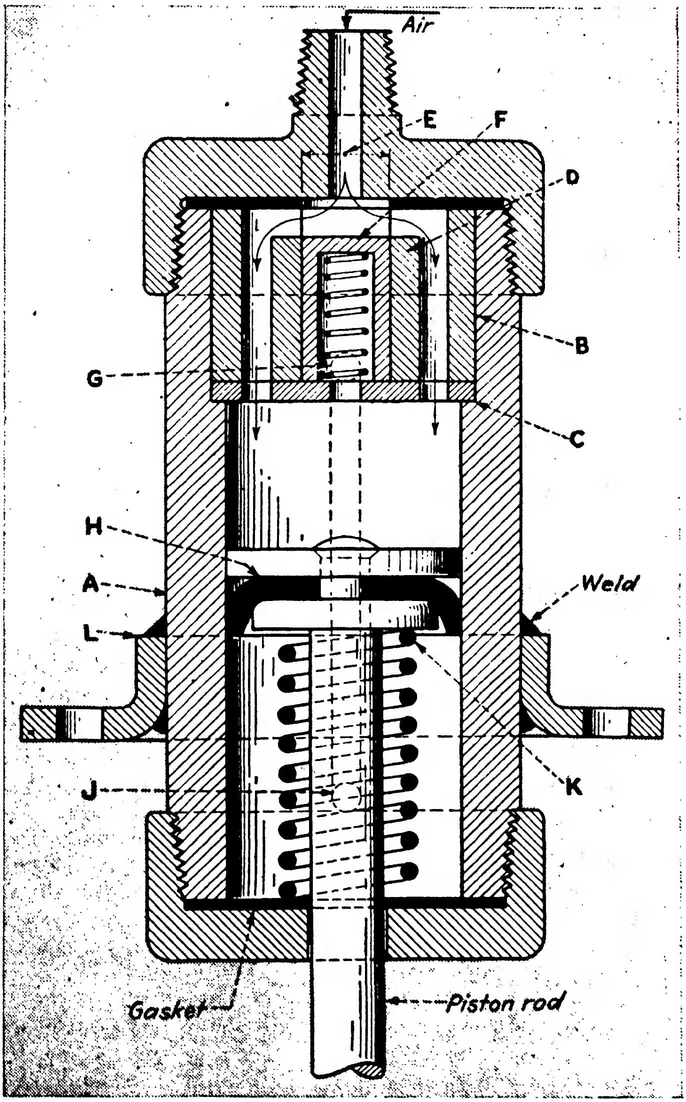


FIG. 113. Compressed-air Cylinder.

body, *A*, of this unit is a suitable length of cold-drawn steel tubing, whose inside diameter is 1½ inches. Parts *B* and *C* are turned on a lathe and press-fitted against a square shoulder turned in the upper end of the cylinder; and these parts have two vent holes, *D*, with right-angled openings into center hole *E*, wherein thimble *F* is situated. A light compression spring is inserted in thimble *F*, and its power is sufficient only to raise the thimble against the upper cap (closing holes *D*) when no compressed air is being injected into the cylinder. Behind thimble *F* is exhaust hole *G*, which leads down the wall of the cylinder to point *J* below piston head *H*. Except for the fact that it is comparatively large (having a head area of 1.767 inches), the piston is similar to the pistons used in ordinary automobile tire pumps; it has a leather washer and is normally positioned against plate *C* (when the air pressure is off) by compression spring *K*, which exerts a power of 8 to 10 pounds.

The ordinary shop pressure of 80 pounds per square inch may be utilized in operating this air cylinder, and thus a piston thrust of 1.767 by 80 pounds, or 141 pounds, is produced. If the operating leverage is arranged to multiply the power three or four times, a holding pressure of 400 to 600 pounds can therefore be obtained.

When air pressure enters the cylinder, thimble *F* is immediately depressed. This opens holes *D* and closes exhaust hole *G*, forcing piston head *H* to move down (and thus operate a clamp or similar mechanism). Then, when the air is shut off, thimble *F* rises instantly, closing holes *D* and opening exhaust hole *G*; this relieves the pressure on piston head *H* and allows compression spring *K* to expand, pulling the piston rod upward.

Mounting brackets *L* make it possible to attach the air cylinder to a suitable base or supporting structure by means of set screws, and they may be welded on the cylinder body at any convenient locations.

OTHER PNEUMATIC UNITS

Those units which enable an air cylinder to function satisfactorily may be listed as follows:

(1) *Air line.* The hose or tube which conducts compressed air to the cylinder.

(2) *Compressor.* The mechanism which compresses air for the cylinder.

(3) *Control valve.* A hand- or foot-operated unit which enables a workman to govern the operations of the cylinder.

(4) *Dial pressure gage.* An instrument which indicates (usually in terms of pounds per square inch) the air pressure that is being admitted into the cylinder.

(5) *Lubricator.* A device used to blow lubricating oil into the cylinder.

(6) *Reducing valve.* A hand-operated unit which will regulate the amount of air admitted into the cylinder.

(7) *Stop valve.* A hand-operated unit which will isolate the cylinder when it is not in use.

Metal tubing often makes the best air line, because it can be sealed to prevent air leakage indefinitely. However, if the line must be moved or handled many times, reinforced rubber tubing may be preferable because of its flexibility.

Almost every modern factory is equipped with air compressors, and it goes without saying that the tool designer should make every effort to provide pneumatic mechanisms which can be operated from them. Regardless of the air pressure used by a given factory, it is generally advisable to allow for a 10 per cent drop in pressure between the compressor and the air cylinder, since some pressure is always lost, owing to the length of the air line.

The physical characteristics of a control valve depend largely on what is most convenient for the worker who must operate the air cylinder. Foot-operated control valves are often preferred, because they leave the hands free for other operations.

Both the lubricator and the reducing valve may be dispensed with in many types of pneumatic mechanisms, because it is often possible to lubricate the air cylinder with an ordinary oilcan and because it is not always necessary to vary the pressure on the work in a jig or fixture.

AIR-OPERATED JIG

An example of how pneumatic mechanisms may be advantageously utilized is indicated in Fig. 114. The tool shown here is a "universal" bearing-shell drill jig, and it has been employed with considerable success because it eliminates the necessity of making separate drill jigs for several sizes of bearing shells. Its function is to drill and tap parting holes in the shells, which have parting widths ranging from 3 to 14 inches.

The jig is rotated 180 degrees by means of a pneumatically operated gear-and-rack arrangement, in order to position the lower half of the bearing shell; then the part is clamped in position against adjustable jaws by means of another air cylinder. Thereafter, the jig is returned to

FIG. 114. Air-operated Jig.

its normal position so that the top half of the bearing shell can be suitably located above its mate, and a third air cylinder is used to clamp the entire assembly together.

The bearing shells have been standardized so that there is the same size of step between the upper and lower halves. Therefore, one setting of the adjustable jaws is sufficient for a production run on a given size of bearing, and the operator is required only to align the end faces.

Control valves for the three air cylinders are at the right-hand end of the jig, and the air cylinder which pushes the bottom casting upward is twice as large as the cylinder which holds the upper shell; this gives the tool adequate resistance to drilling pressures.

Bolts clamp the bearing halves together and serve as dowel pins to

maintain alignment. Holes are tapped through both top and bottom casting lugs, and then the assembly is taken apart to babbitt the two halves separately. After babbitting, a clean-up cut is required on each of the parting faces so as to leave a $\frac{1}{64}$-inch gap between the shells when they are bolted together. The top and bottom halves of the bearing are clamped together in a vertical position, and then the holes are retapped from the bottom side. This leaves, in the top half, a thread which has lost about $\frac{1}{64}$ inch of its lower face, the pitch diameter being unchanged, and the consequent looseness on the lower face of the thread makes it possible for the two halves to be pulled tightly together —while the fullness on the pitch diameter of the bottom face of the thread acts as a dowel pin to keep the shell halves in perfect alignment.

The main frame of the jig is a welded-steel assembly mounted on a 24″ by 59½″ by 2″ steel base plate. This frame supports the jig body between trunnion bearings, one of which has an extended shaft for the pinion that is rotated by a vertical rack fixed to the end of the piston rod of an 8″ by 7″ air cylinder mounted vertically on the base plate. In the drilling position, the jig body is swung down against a stop on the base plate and this assures positive angular alignment of the work with the drill spindle.

Hydraulic Mechanisms

Hydraulic mechanisms are so closely related to pneumatic mechanisms that units of the two are sometimes interchangeable. This is explained by the fact that the air used by pneumatic mechanisms is a fluid, as are the oils or other liquids in hydraulic mechanisms.

The latter have never been used to a great extent in connection with jigs or fixtures, because they are comparatively expensive. However, they are indispensable for certain types of work because they are much more controllable than pneumatic mechanisms.

When compressed air is released in an air cylinder, several seconds of time may elapse before there is sufficient pressure to actuate the piston. Then the piston moves swiftly; and if the air pressure has not been properly regulated, it is likely to damage delicate pieces of work or subject the tool to undesirable stresses.

On the other hand, a hydraulic cylinder responds promptly to each increment of fluid pressure. Accordingly, its piston can be moved slowly and steadily; and if there is danger of building up too much pressure, the piston may be halted immediately.

These primary differences between pneumatic and hydraulic mechanisms are due to the fact that air is compressible whereas hydraulic fluids are incompressible.

ELEMENTS OF HYDRAULICS

Like pneumatic power, hydraulic power is created by actuating a piston within a cylinder. However, the hydraulic cylinder is normally double-acting because pressure may be applied to both sides of its piston for power in either direction.

The fluid which transmits pressure for the hydraulic piston is usually either a low-viscosity mineral oil or a mixture of alcohol and glycerine; and since both of these are incompressible fluids, the power delivery of any hydraulic cylinder is directly proportional to the applied pressure. Therefore, a power ratio similar to a gear ratio may be obtained by varying the piston area of a hydraulic cylinder, providing the fluid operating pressure remains constant. For example, in a cylinder having a constant fluid pressure of 1,000 pounds per square inch, a piston with a three-square-inch area would deliver a force of 3,000 pounds while a piston with a half-square-inch area would deliver a force of only 500 pounds.

APPLICATIONS OF HYDRAULIC POWER

Figs. 115, 116, 117, 118, and 119 represent the fundamental methods of transmitting hydraulic power. If these diagrams are carefully studied along with the following explanations, the reader should be able to understand any of the hydraulic mechanisms that may be encountered in designing and constructing jigs and fixtures.

The simplest form of hydraulic-power transmission is indicated in Fig. 115, which shows the cross sections of two interconnected hydraulic cylinders. If pressure is applied to piston 2, fluid will be transferred from *A* to *B* and piston 1 will be forced to move to the right, displacing further fluid from *C* to *D*. Since both pistons are of equal area, any movement of piston 2 will cause an identical movement of piston 1 (or *vice versa*); and because the fluids in the cylinders are incompressible, any one of the pistons will be locked at whatever position it occupies when mechanical power locks its mate.

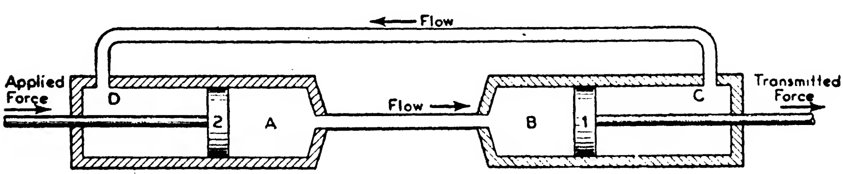


FIG. 115. Interconnected Hydraulic Cylinders.

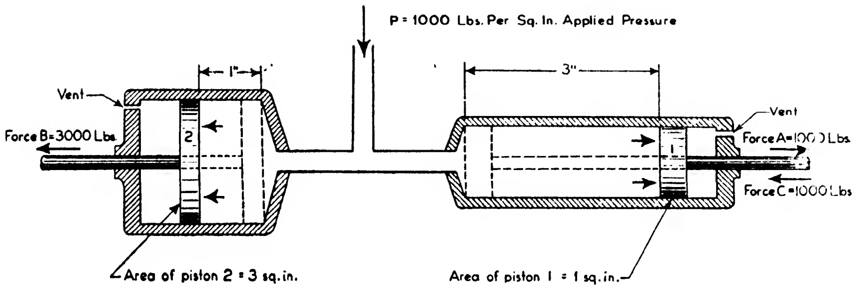


FIG. 116. Simplest Form of Hydraulic Pressure Ratio.

Fig. 116 indicates the simplest form of pressure ratio, and represents a force transmitted in two ways:

(1) If outside pressure, *P*, is applied at and distributed to pistons 1 and 2, the forces *A* and *B* on the piston rods will be equal to pressure *P* in pounds per square inch multiplied by the area of each of the respective pistons. Consequently, if the area of piston 1 is taken as one square inch, force *A* will be equal to the pressure in pounds per square inch times area, or 1,000 pounds. Similarly, if the area of piston 2 is taken as three square inches, force *B* will be equal to three times 1,000 pounds, or 3,000 pounds.

(2) If the opening for pressure *P* is closed and an incompressible fluid fills the space between pistons 1 and 2, force *C* (or 1,000 pounds) exerted on piston 1 to the left would transmit a pressure of 1,000 pounds per square inch (or a total of 3,000 pounds of pressure) against the head of piston 2.

An example of force acting through a distance is shown in Fig. 117. This represents "work" (as opposed to pure mechanical pressure), and

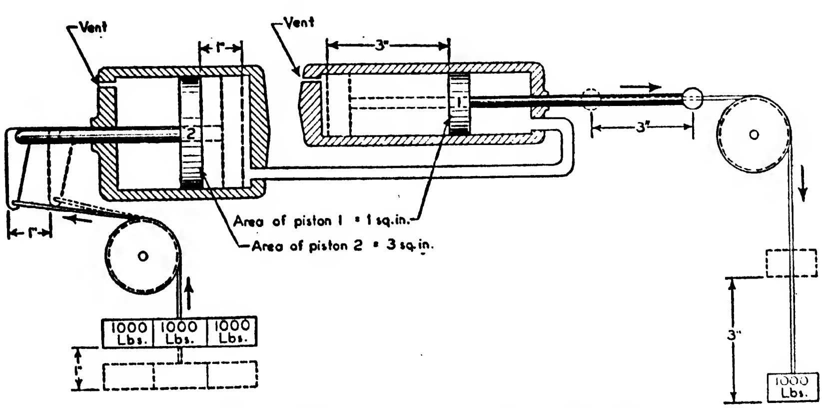


FIG. 117. A Force Acting through a Distance.

work output always equals work input less friction losses. Here we will assume that piston 1 has an area of one square inch while piston 2 has an area of three square inches. Therefore, if a force of 1,000 pounds is applied to move piston 1 a distance of one inch, three cubic inches of fluid will be displaced; and this will force piston 2 to move to the left one inch to provide room for the displaced fluid. If no frictional losses are assumed, it can then be said that piston 1 has accomplished 3,000 inch-pounds of work.

Fig. 118 shows a hydraulic mechanism with a source of regulated pressure and a four-way valve. Here a pressure pump draws hydraulic fluid from a reservoir and forces it through a pressure system to the main operating or selector valve. If no units are being used, all fluid

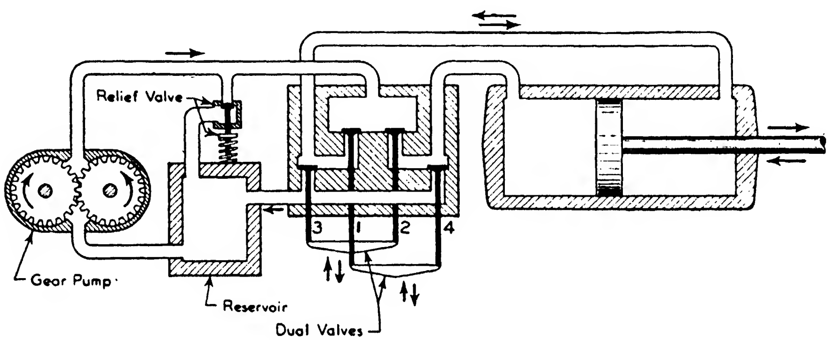


FIG. 118. Hydraulic Mechanism with Source of Regulated Pressure and Four-way Valve.

will be returned to the reservoir by means of a relief valve, which continually "bleeds off" excess fluid over its pressure setting. The selector valve shown in this diagram is termed a *four-way valve* because its action is in four directions, and it provides for motion of the piston in either direction under power. Valves 1, 2, 3, and 4 are mechanically interconnected so that they will open and close in pairs. When valves 1 and 4 are opened, fluid is admitted under pressure by the pump through valve 1, thence through interconnecting tubing to the space back of the piston, while fluid is drained from the front of the piston through valve 4 to the reservoir. This forces the piston to move to the left. Conversely, when valves 2 and 3 are open, the piston is forced to move to the right. If the operating valve is properly manipulated, the piston can be stopped at any point in its stroke (provided, of course, that there are no leaks in the system).

The hydraulic "debooster principle" is illustrated in Fig. 119. Here fluid enters the interior of a sleeve cylinder and acts against the inside

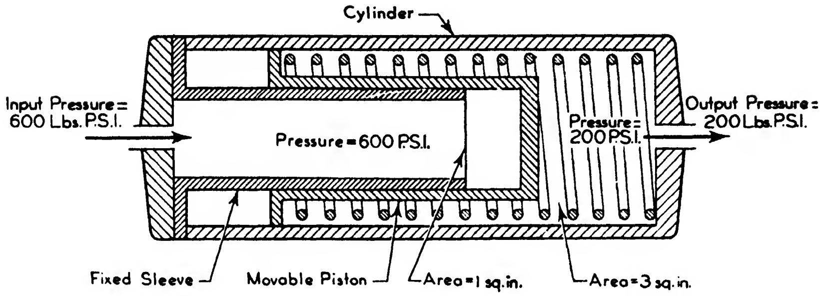


FIG. 119. Hydraulic "Debooster" Principle.

head of a sleeve piston, forcing the piston into a cylinder of large diameter. If we assume that the area of the inside sleeve piston is one, and that the inside area of the large cylinder is three, the pressure ratio between the input on the sleeve piston and the output pressure from the cylinder will be in the order of the inverse ratio of the areas, or three to one. Thus, an input pressure of 600 pounds will deliver an output pressure of 200 pounds per square inch.

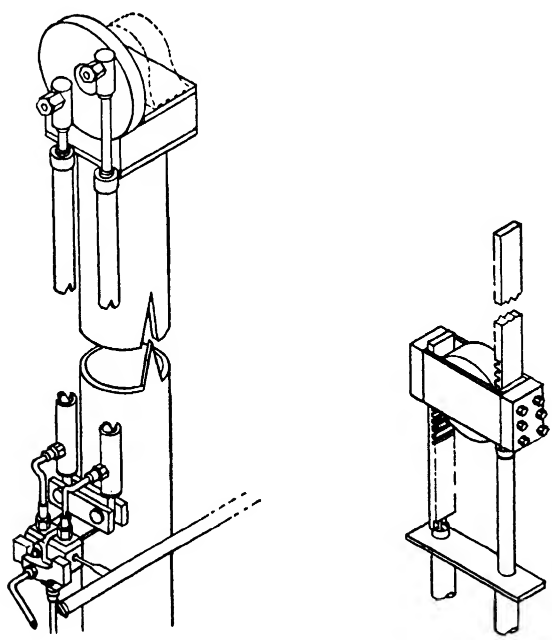


FIG. 120. Hydraulic Mechanism for Picture-frame Fixture. ***Left:*** **Wheel mechanism.** ***Right:*** **Pinion-gear mechanism.**

HYDRAULIC MECHANISMS IN USE

Fig. 120 shows how hydraulic mechanisms are generally employed in connection with jigs and fixtures. Two hydraulic cylinders, controlled by a four-way valve, are used to turn the trunnion mechanism of a large picture-frame fixture, such as was indicated in Fig. 64. The cylinders are arranged so that their pistons work in opposite directions; and, as illustrated, the piston rods can be adjusted to give rotary motion to either a wheel or a pinion gear mechanism. The pinion gear setup is generally preferred because it allows 180 degrees of rotation, whereas the wheel arrangement permits only 120 degrees of rotation.

If necessary, a hand-operated worm-gear mechanism could be used in place of the setups indicated in Fig. 120; but it would cost almost as much as the hydraulic mechanism, and it could not be controlled as smoothly or as accurately. Pneumatic mechanisms are often unsuitable for this type of work because, as previously explained, they function too spasmodically.

CHAPTER 9

PLASTICS

Uses of Plastics

IF WE WERE to believe all that has been said in behalf of plastics, we might conclude that any manufacturer who continues to use metals for any purpose whatsoever is a reactionary. But the truth is that plastics as a whole are suitable only for special applications.

Where they can be used, plastics may be both physically and economically superior to all other types of materials. At this time, however, there is no synthetic material which can be employed as cheaply and efficiently for so many different types of work as iron and steel.

In so far as jigs and fixtures are concerned, plastics have been used mainly to construct those tools which do not have to withstand great loads or impacts—drill jigs, inspection fixtures, small holding jigs, and trim fixtures. But this is probably due largely to cost considerations, because there are a number of plastic materials which have much strength and good impact resistance.

General Types of Plastics

Technically speaking, the term *plastics* denotes virtually all types of synthetics or materials not directly produced by Mother Nature. However, in the more restricted sense that is applicable here, a plastic is an organic substance created in a chemical laboratory by enlarging or rebuilding the molecules of nonmetallic materials containing various percentages of carbon.

Three general types of organic plastics have been successfully utilized for the purpose of constructing jigs and fixtures:

(1) *Moldable thermosetting plastics* are materials which can be formed by casting. They will first soften when heated; then when the heating is continued, they will go through an internal chemical reaction and harden—never to repeat the process.

(2) *Moldable thermoplastics* can also be formed by casting. They are distinguished from the first group of plastics in that they can be

melted, molded, and cooled repeatedly without being permanently hardened.

(3) *Plastic adhesives* are resinous materials which can be used to unite other materials.

Since chemistry is outside the province of this book, we will not endeavor to tell how plastics are produced. However, we will explain how specific plastics of each general type have been successfully utilized for tooling purposes so that the reader will be able to evaluate those plastics which he may encounter later.

TOOLITE

Typical of the moldable thermosetting plastics that have been used in constructing jigs and fixtures is *Toolite*. Its most important physical properties are:

Weight (after hardening)	77.38 lb./cu.ft.
Specific gravity	1.24
Oil absorption	Slight
Compressive strength	15,000–20,000 lb./sq. in.
Modulus of rupture	3,330 lb./sq. in.
Tensile strength	2,160 lb./sq. in.
Machinability	Good
Resistance to hot flame	Chars at 400°F.
Resistance to acid and alkaline solutions	Excellent
Resistance to common solvents	Excellent
Effect on metal inserts	Corrodes plain steel
Electrical conductivity	None
Contraction after curing	1/32 in./ft.

As the reader can see, Toolite is extremely strong, although it is lighter than either aluminum or magnesium. Therefore, it has been extremely useful in fabricating tools such as lathe fixtures and drill jigs.

Publicists have stated that the process of molding Toolite is as simple as baking a cake. This, of course, is an overstatement. But it is true that the necessary procedure can be quickly mastered by unskilled workers. Fig. 121 shows the required layout of equipment for a Toolite laboratory.

Molds for casting the plastic can be made from any rigid material that will produce a smooth surface—for example, wood, plaster, metal, glass, or Toolite itself. The individual mold should have a two-degree draft and a 1/8-inch radius for each corner or edge, so that plastic castings can be readily removed therefrom. Two or three coats of lacquer

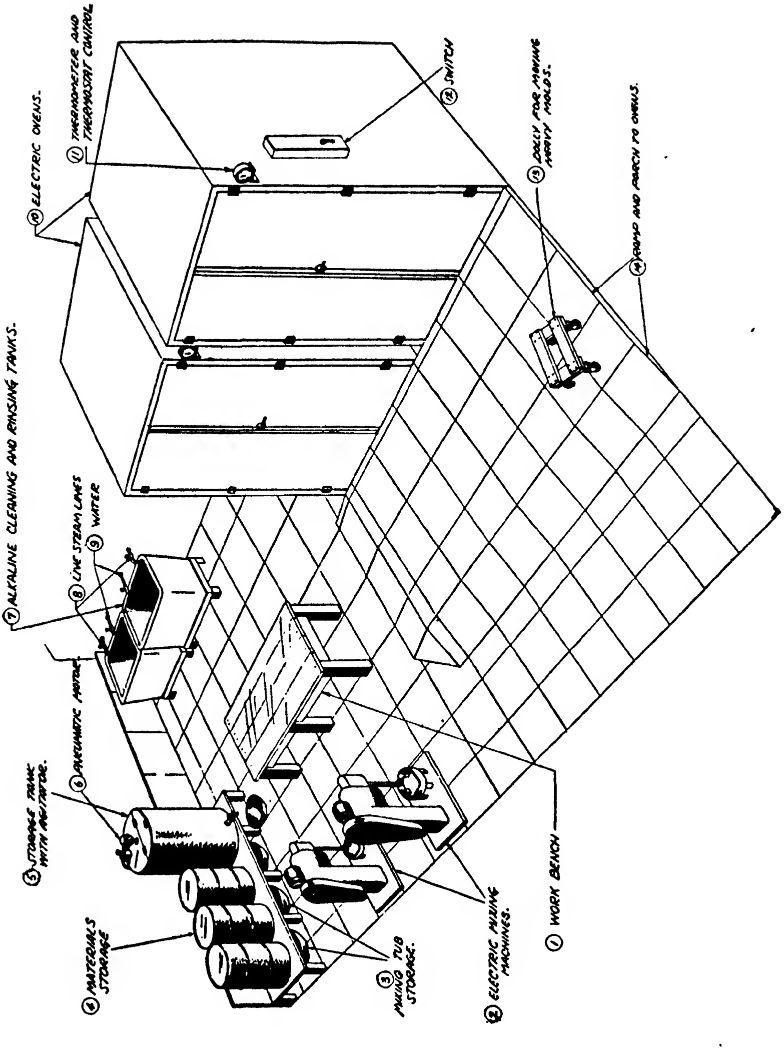


FIG. 121. Toolite Plastics Laboratory.

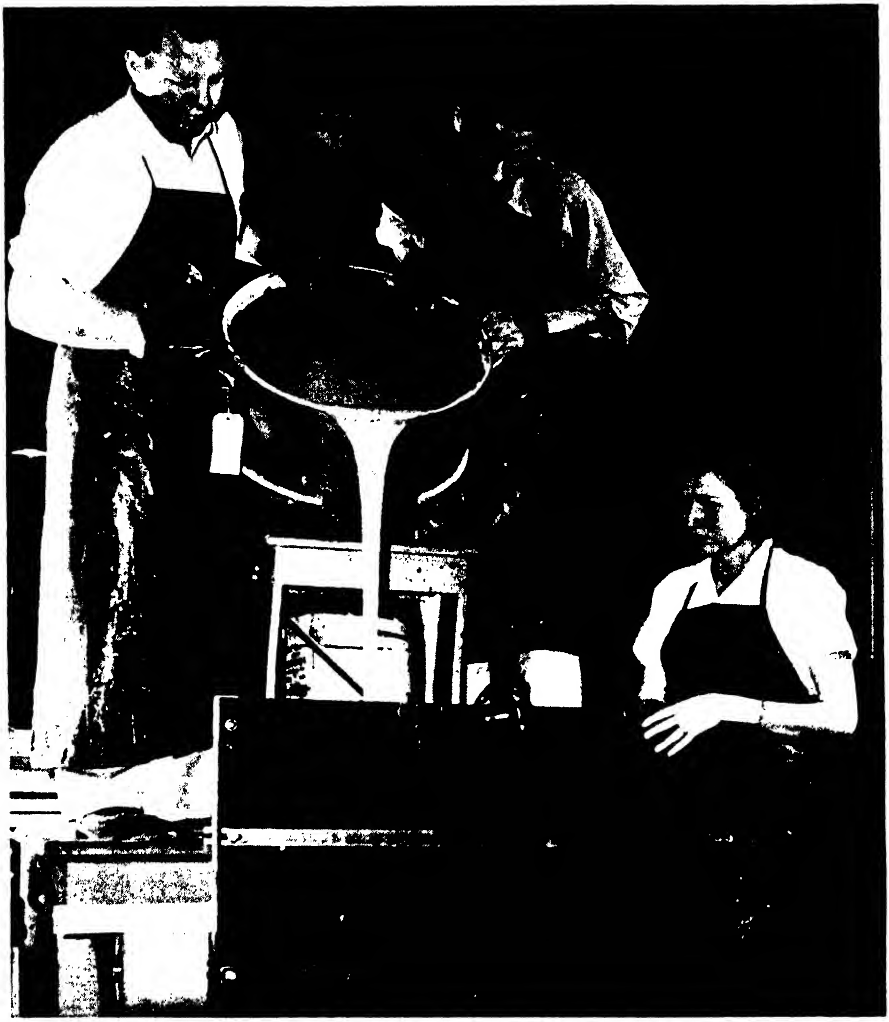


Fig. 122. Pouring Toolite Plastic.

will protect the mold surfaces; and, over these, a coating of wax should be applied before making a casting. The wax serves as a parting agent.

Toolite mix should be stirred by itself in an ordinary bakery cake mixer for a short period of time; then a catalyst, which causes the material to harden, should be thoroughly stirred into the mix.

The plastic should be poured into the mold as soon as it begins to thicken; and if the casting is to have maximum strength, it should be poured slowly down the side of the mold, as shown in Fig. 122, to trap

the fewest air bubbles. The casting can be "cured" simply by leaving the plastic in the mold for a period of 24 hours at room temperature; but best results are obtained by allowing it to stand at room temperature for only six hours, then placing it in a low-temperature oven, for a period of four to six hours.

If necessary, Toolite castings can be readily machined to extremely accurate dimensions, as indicated in Fig. 123. Since these castings are not subject to the expansion and contraction that characterizes metal parts, they can retain those dimensions within very close tolerances.

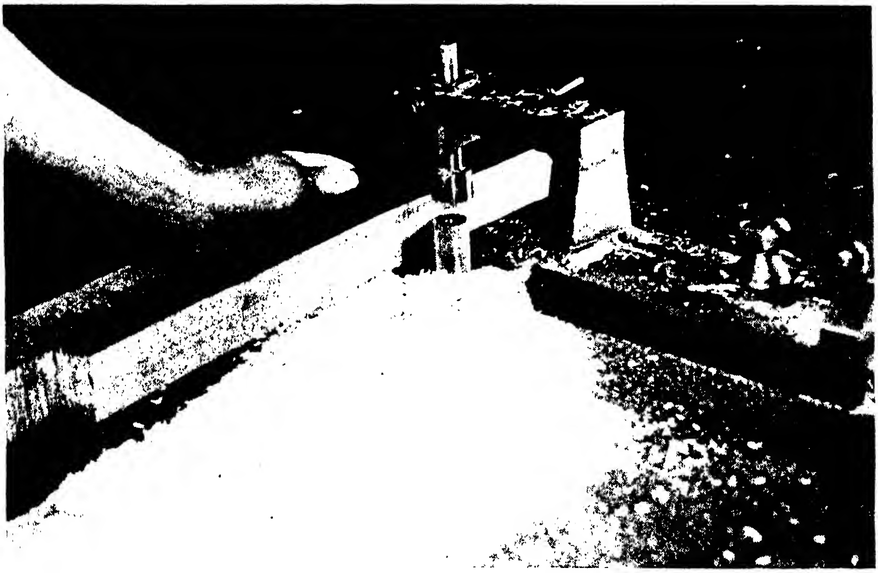


Fig. 123. Machining a Toolite Casting.

The initial costs of Toolite are appreciably less than the initial costs of most metals. However, it should be recalled that virtually all metals can be salvaged by melting, whereas thermosetting plastics become infusible as soon as they have been cast and cured.

Like many other high-strength plastic articles, Toolite jigs or fixtures are likely to become marred or chipped when they are subjected to rough handling. Such damage can sometimes be prevented by reinforcing the exposed plastic surfaces with metals. If this practice is impractical, repairs can often be made by filling in the marred or cracked areas with freshly mixed batches of plastic. The repaired areas should be cured by one of the previously described methods; then, if dimensional accuracy is essential, they can be appropriately machined.

PLASTIFORM

Since moldable thermosetting plastics are frequently uneconomical because they cannot be salvaged, it stands to reason that moldable thermoplastics, which can be reclaimed like metals by melting, should have a bright future in the field of plastic tooling. However, at this writing, there are only a few thermoplastics with sufficient strength for tooling purposes. Of these, probably the best is *Plastiform.*

The more important physical properties of Plastiform are:

Compressive strength	15,000 lb./sq. in.
Weight	90 lb./cu. ft.
Izod impact resistance	1/3 ft.-lb.
Melting point	240°F.
Resistance to acids and alkalies	Excellent
Resistance to water and oils	Excellent
Shrinkage on application	None
Effect on ordinary metal inserts	None
Machinability	Excellent
Time required to cool	4 minutes
Warpage	None
Abrasive characteristics	None
Reclaimability	100%

Accordingly, it might be said that a Plastiform tool is better than the average thermosetting plastic tool whenever high operating temperatures and extreme lightness are not required.

Plastiform is prepared for casting simply by melting in a double boiler whose outer container is filled with an oil bath. Either gas or electricity may supply the necessary heat, and scraps of previously used materials can be placed in the boiler along with fresh batches of the plastic without using additives such as are sometimes required in remelting metals.

The necessary molds can be made from metals, magnesite, glass, plaster, cardboard, wood, or thermosetting plastics. If the mold is of a porous material, such as cardboard or wood, it should be sealed with two or three coats of raw linseed oil and turpentine mixed to equal proportions. Any good high-gloss wax paste can be used as a parting agent in the mold.

When extreme contours or offsets are to be cast, the Plastiform mold should be preheated to approximately 120°F., to prevent flow lines by increasing the solidifying time of the plastic.

If no shrinkage is permissible, best results can often be obtained by brushing or spraying Plastiform into a mold. An ordinary paint brush

may be used, and the mold surfaces should be coated rapidly. Successive coats will build up the desired wall thickness.

A hollow casting can be made without a core by filling a mold with Plastiform and allowing it to stand until the desired wall thickness has been attained. Excess material in the center of the casting can then be poured off before it solidifies.

FIG. 124. Plastiform "Saw and Trim" Fixture.

Shell-type castings are made by partly filling a mold with Plastiform and tilting it so that the material will flow over the appropriate surfaces. Additional pouring and tilting will build up the necessary wall thickness.

Plastiform can also be used to make castings or form protective coverings by dipping. For this reason, the mold or object to be pro-

tected should be warmed and then immersed rapidly and successively in the molten plastic until the required wall thickness has been attained.

When it is to be cast in the ordinary manner, Plastiform should be poured steadily without splashing until the mold is completely filled. Slow or intermittent pouring will cause flow lines, while excessively fast pouring might cause air bubbles to be trapped within the casting.

The most important thing to remember in casting Plastiform is that the thermoplastic will pick up each and every minute detail on the surfaces of the mold. For this reason, the surfaces of the mold should be as smooth as the surfaces desired on the finished product.

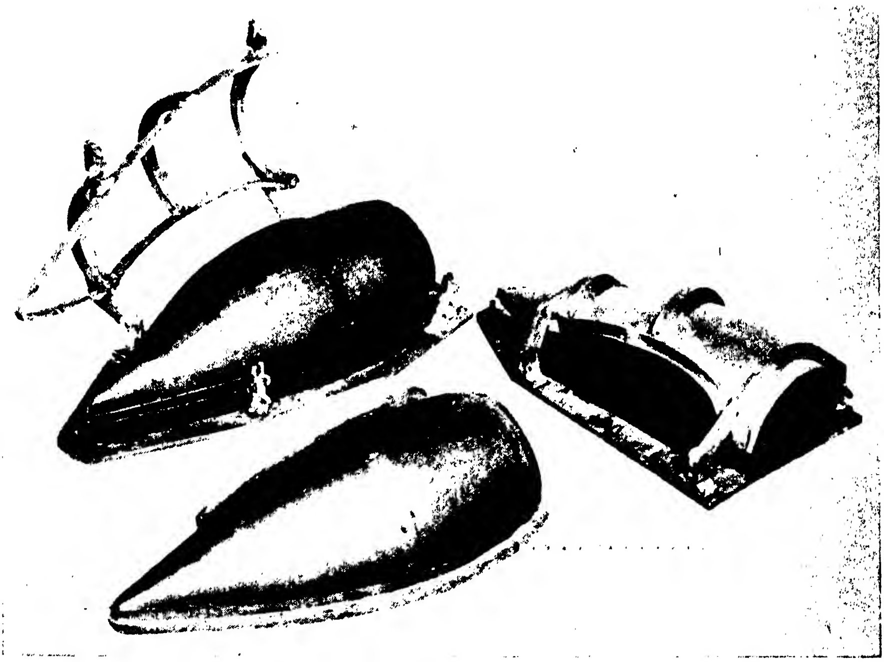


FIG. 125. Plastiform "Drill, Trim, and Scribe" Fixture.

Because there is no appreciable shrinkage in Plastiform, suitable drafts should be made on all molds so that the plastic castings can be easily removed therefrom. The finished castings can be machined like wood, and polished by rubbing briskly with steel wool.

Slight defects on Plastiform castings can be readily patched by filling in with new material, which can be heated and worked with an ordinary soldering iron. Large recesses can be filled in with a paint brush, or by pouring the molten material into the given area, because a bond will be formed immediately.

Figs. 124 and 125 show combination fixtures of the types that can be easily fabricated by casting Plastiform.

THE METLBONDS

Outstanding among the plastic adhesives that have been utilized for tooling purposes are the *Metlbonds,* principal types of which are:

(1) The original high-pressure, high-temperature, single-phase, synthetic-rubber-base type, which requires 100 lb./sq. in. curing pressure at 330°F. for 20 minutes. This type is normally sprayed on the parts to be bonded.

(2) A low-pressure, high-temperature, two-phase type, which requires 15 lb./sq. in. curing pressure at 330°F. for 20 minutes. It comprises a synthetic rubber component, which is sprayed, and a resinous component, which is brushed onto the parts to be bonded.

(3) A tape type which requires 250°F. curing temperature at 100 lb./sq. in. pressure. This type is generally used for bonding parts containing certain organics which become unstable at temperatures above 350°F.

(4) A tape type which requires a 330°F. curing temperature at 100 lb./sq. in. pressure. This type bonds parts so as to provide a higher shear strength and better heat resistance than will the other tape type.

(5) A very low-pressure, high-temperature type, which requires a minimum curing pressure of 1 lb./sq. in. at a temperature of 330°F. The shear strength of this type is approximately two thirds that of the first two types.

Although they were created for the purpose of bonding metals, each of these types can be used for uniting numerous solids—such as Fiberglas, cast plastics, wood, and rubber.

The high-strength Metlbonds are of particular value in building up certain types of metal structures because they can economically produce joints with shear strengths of as much as 3,000 pounds per square inch, which is greater than the shear strengths of many of the metal joints that can be made by riveting and welding.

Moreover, the Metlbonds do not become extremely brittle after curing, as do many other high-strength plastic adhesives. Brittle structural joints are usually undesirable, because they have low impact and peel resistances.

The specific procedure followed in utilizing Metlbonds depends largely upon the nature of the materials to be bonded. For example, the bond between synthetic rubber Metlbonds and glass fails when subjected to intense sunlight; therefore, the resinous form of the adhesive

should be used next to glass. On the other hand, the adhesion of synthetic rubber Metlbonds to transparent thermosetting plastics seems to be unaffected by sunlight.

A small hydropress (such as is shown in Fig. 126) and a Dow Therm heating unit will supply the heat and pressure necessary for "curing" parts that are to be Metlbonded. The heating unit is essentially a steam boiler, which uses a liquid other than water so that it can operate at

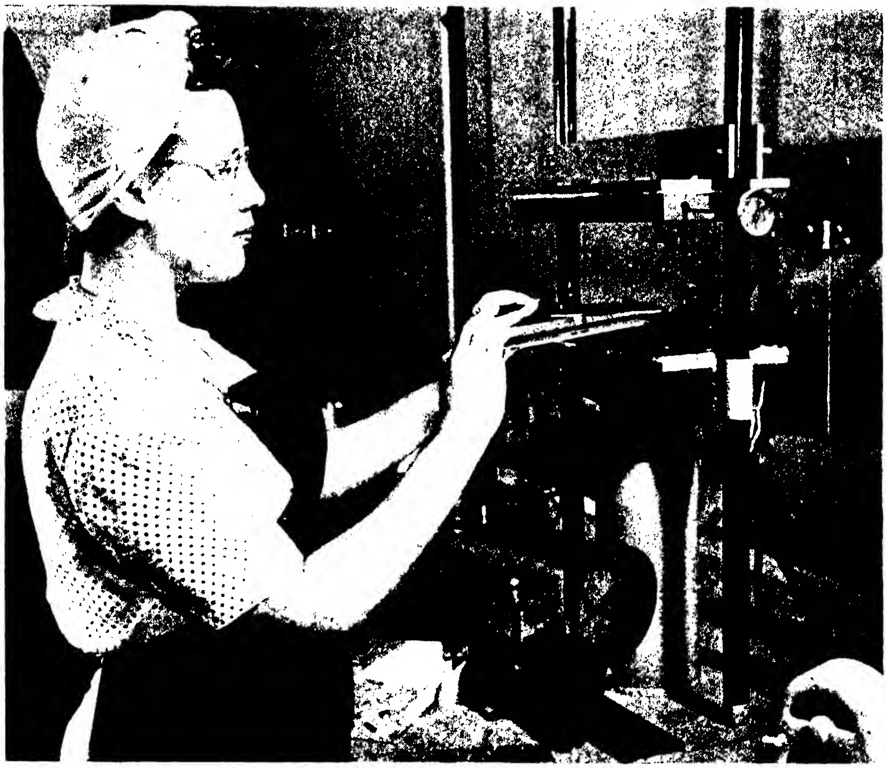


FIG. 126. Hydropress for Curing Metlbonded Parts.

higher temperatures. Gas is used to heat the Dow Therm liquid to its boiling temperature of 350°F., and this further eliminates the high pressures involved in using steam. The heated liquid should be piped to the top platen of the hydropress and circulated by means of an electrically driven pump. "Adapter plates" will make it possible to heat the variety of tools necessary for holding the Metlbonded parts on the upper platen only. The lower platen should never be heated, because this might cause partial curing of the adhesive before pressure could be applied. Fiberglas pads on the lower platen will serve as heat insula-

tors and pressure equalizers. The parts to be Metlbonded should be thoroughly cleaned before they are sprayed or otherwise coated with the adhesive; and after the adhesive has dried, the parts should be assembled and placed in the hydropress for curing with heat and pressure. Regardless of the complex nature of the parts, the hydropress can turn out one complete assembly every three minutes.

When used to bond plastics to aluminum, or aluminum to steel, the Metlbonds have sufficient flexibility to allow for the differences in the thermal expansion coefficients of the two materials and may serve as insulators to prevent electrolytic corrosion. Accordingly, in one large factory the Metlbonds are now being used to cement steel sheets to moldable plastic tools—thereby reducing the tendency of the latter to become marred or broken when subjected to rough handling.

The resinous Metlbonds are also being used to produce plastic laminates, which have unprecedented lightness and strength. At present, the best of these is *Conolon.* Made by impregnating extremely fine filaments of Fiberglas with a resinous type of Metlbond, Conolon has the following important physical properties:

Maximum modulus of elasticity	4.7×10^6
Maximum tensile strength	120,000 lb./sq. in.
Maximum compressive strength	56,000 lb./sq. in.
Specific gravity	1.64
Resistance to common acids, alkalies, and solvents	Good
Resistance to water, oils, and cutting compounds	Good
Maximum Rockwell hardness (M-scale)	110
Maximum impact resistance, edgewise .	126 ft.-lb./in.^{2}
Ultimate bearing strength	82,000 lb./sq. in.
Resistance to vibrations	Excellent

As this table indicates, the laminate has strength properties which make it comparable to steel, although it is lighter than aluminum. However, it will probably not be widely used for some time because the cost of Fiberglas is comparatively high.

Fiberglas can be used as received from the mills in making Conolon; but, if it is contaminated with grease or dirt, the material should be thoroughly dry-cleaned with a good naphtha-type solvent before it is used.

The fibers are impregnated simply by passing the fabric through a bath of Metlbond resin, which is usable at room temperatures, and between two rubber squeegees, which remove excess resin, as indicated

in Fig. 127. Then the material is air-dried for a period of 24 hours, or oven-dried for a period of 20 minutes at a temperature of 140°F. When it has been dried, the fabric should be suspended so that it will not wrinkle, sag, or be subjected to dust or moisture.

The procedure followed in laminating Conolon varies in accordance with the nature of the parts to be fabricated and the stresses to which

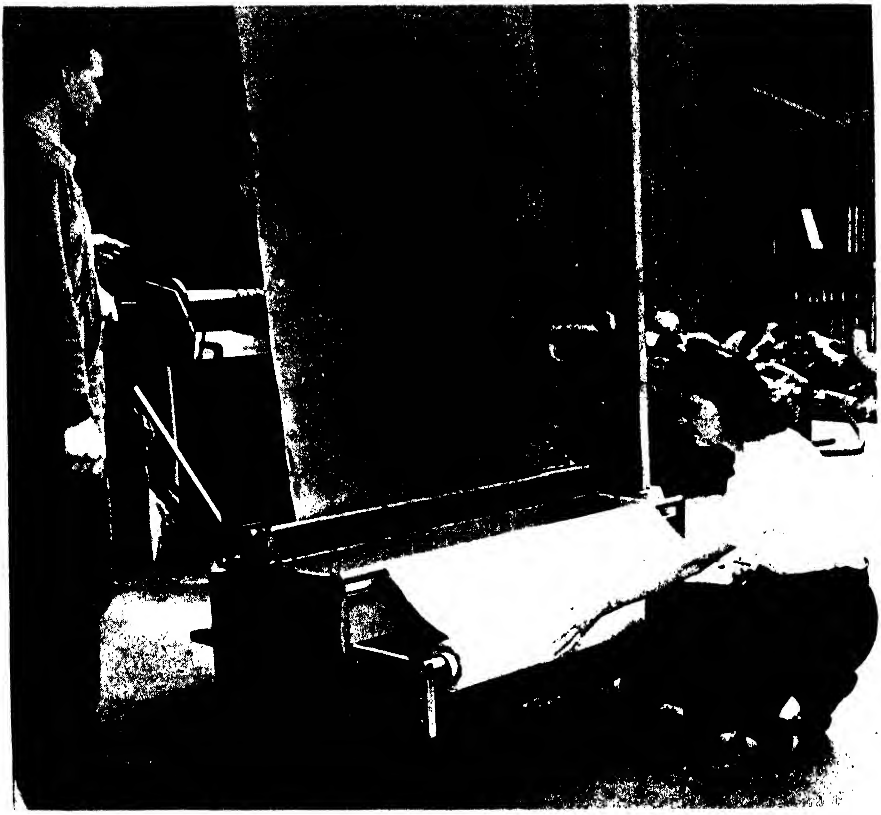


FIG. 127. Impregnating Fiberglas with Metlbond Resin.

they will be subjected. Generally speaking, the lamination should be such that all of the fabric fibers will be at an angle to one another.

The curing may be accomplished either in a vacuum bag or in a hydraulic press at a pressure of 10 to 15 pounds per square inch and a temperature of 300°F. (+25° or —10°) in a period of approximately 30 minutes, depending on the thickness of the laminate.

Precautions that must be observed in order to obtain good Conolon laminations are:

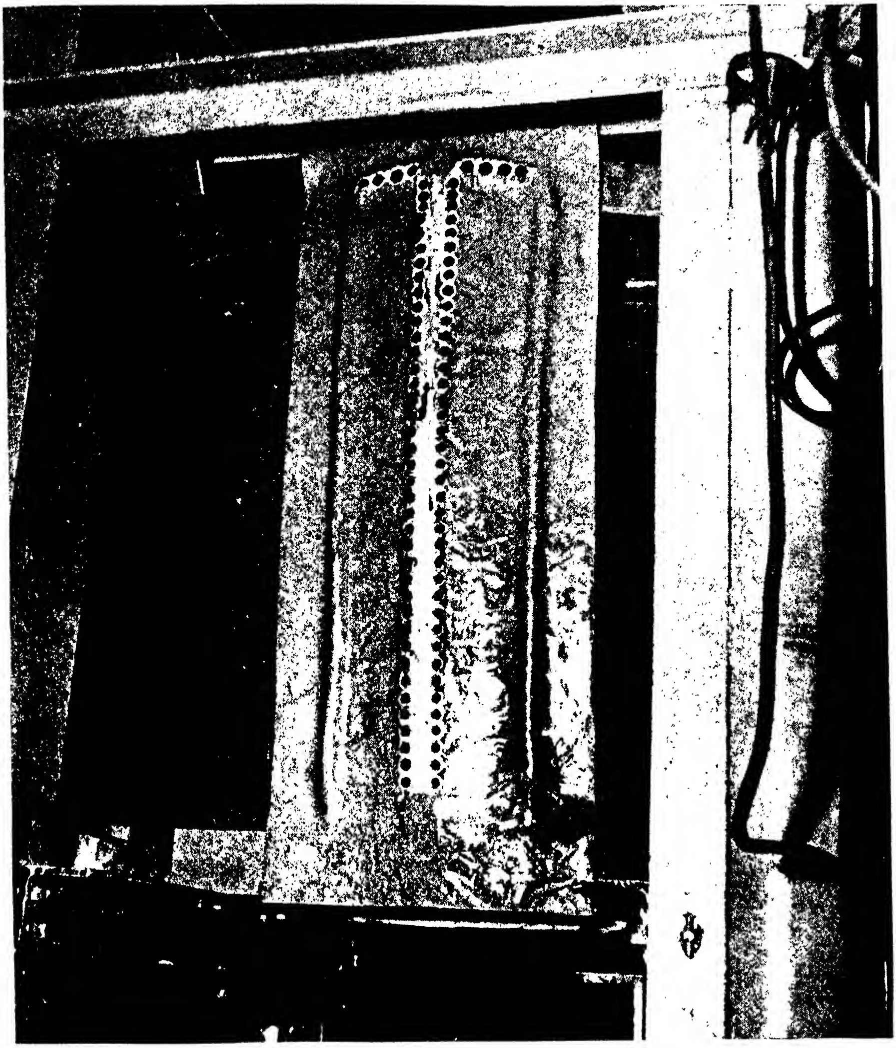


FIG. 128. Conolon Drill Jig.

(1) The fabric must contain the correct amount of resin to produce a finished laminate containing 27 per cent ($\pm$7 per cent) solid resin.

(2) The resin-impregnated fabric must be stored in a sealed container at a room temperature of approximately 75°F. when it is not to be used immediately. In no case should the impregnated fabric be stored longer than one month or at temperatures of more than 75°F.

(3) Extreme care must be exercised in building up the laminates to make sure that the fibers are laid in the right directions, because the

unidirectional Fiberglas fabrics have 100 per cent of their strength concentrated in one direction.

(4) The molds must be designed so that they will have sufficient strength to withhold the pressures involved in curing the laminates. Although they are comparatively low, such pressures may constitute a very large total force which will cause distortion in sizable molds.

Because their initial cost is high, the Metlbond laminates are now used only for the production of contoured parts whose fabrication with other materials would require excessive investments in time, tools, and labor. In such circumstances, the initial cost can be ignored because low-pressure plastic laminates are probably the cheapest of all materials to fabricate in complex shapes.

Fig. 128 shows an open-type drill jig which was made from Conolon. This jig has been used for locating and drilling 86 holes in the double-curvature surface of an airplane wing; and it was economical, despite the initial cost of its materials, because its fabrication necessitated only a few hours of work—whereas a metal drill jig of this type might have required weeks of concentrated effort.

Design Considerations

In designing plastic tools, the main considerations are the physical limitations of the materials which must be utilized. Because of the large and varied number of plastics now on the market, it is naturally impossible to list all such limitations in a book of this size. However, Fig. 129 indicates those properties which characterize the most common chemical types of plastics.

The physical limitations of a material make it necessary to observe special precautions, such as the following:

(1) Do not call for re-entrant curves or undercuts on small diameters. These can sometimes be made on large diameters, but they are invariably expensive.

(2) Do not call for thin walls adjacent to thick sections. Unequal shrinkage causes cracks.

(3) Do not call for sharp inside corners where fillets are permissible. Sharp corners may cause weak walls.

(4) Do not call for long side holes which have no provisions for support. Such holes can be made, but they usually increase the cost of the plastic part.

(5) Do not call for components with holes near their edges or faces. The thin sections adjacent to such holes will tend to blister or crack.

Class of plastics	Shock resistance (impact-Izod)	Tensile strength	Flexural strength	Cold flow	Hardness (Rockwell)	Heat resistance (Utility under continuous heat)	Dimensional change on aging	Thermal insulation	Specific gravity	Flammability	Color possibilities	Color stability	Utility around inserts	Ease of molding	Water resistance (absorption)	Alkali resistance	Acid resistance	Organic solvent resistance	Loss factor, 60 cycles/sec.	Loss factor, megacycle/sec.	Resistivity	Dielectric strength
Phenolics: general purpose....	3	1	3	1	2	2	4	1	2	4	2	2	3	1	4	3	3	2	3	2	3	3
low loss............	3	2	5	1	2	3	2	2	4	2	4	4	3	3	1	2	2	2	1	1	1	1
heat resistant......	5	6	6	1	2	1	1	2	4	1	4	3	2	3	2	2	2	2	5	4	5	5
heat resistant with improved impact...	2	3	1	1	2	1	1	2	4	1	4	3	1	4	2	2	2	2	5	4	5	5
acid resistant; alkali resistant.....	5	5	4	1	1	3	3	1	1	3	3	3	4	2	3	1	1	1	3	2	2	3
medium shock resistant...........	2	4	3	1	2	4	5	1	2	5	4	3	1	3	5	3	3	2	4	3	4	4
high shock resistant..........	1	4	4	1	2	4	5	1	2	5	4	3	1	4	5	3	3	2	4	3	4	4
Urea................	4	1	2	1	1	5	6	1	3	3	1	1	5	2	4	4	4	2	2	2	2	2

FIG. 129. Physical Properties of Common Plastics.

The numbers 1 to 6 represent highest to lowest in order of merit. Relationships are qualitative and variation in formulation may alter relative position.

(6) Do not call for projecting inserts too close to the edge ot a molded part.

(7) Do not call for oblique holes. These are both difficult and expensive to make.

(8) Do not call for tolerances closer than +0.002 inch on small dimensions or +0.005 inch on large dimensions, unless they are absolutely necessary. Plastic tools can be fabricated to dimensions that are accurate within a fraction of a thousandth of an inch, but they are very expensive.

(9) Do not call for sharp entering corners on holes that are to be tapped. All tapped holes should be countersunk so that their edges will not chip when the tap is withdrawn.

(10) Do not call for molded holes which are 1/16 inch or less in diameter and more than 2½ times that diameter in length. Such dimensions will cause untold fabrication difficulties.

(11) Do not run an outside thread all the way down the face of a boss. Such a thread will necessitate a knife edge on the mold where the thread starts away from the surface, and knife edges are always trouble points because they will break off.

CHAPTER 10

MISCELLANEOUS JIGS AND FIXTURES

Fixtures for Induction Heating

BECAUSE FIXTURES must withstand extremely high temperatures without absorbing too much of the flux energy that is needed by the work, those used in connection with high-frequency induction heating operations should be made largely from nonmetallic materials such as asbestos board.

Fig. 130 shows how asbestos-board fixtures may be built up. As indicated, a few small metal parts (such as bolts, screws, and angle plates) may be used; and where they are necessary, these parts should be of nonmagnetic materials such as brass and aluminum (both of which have low heat-absorption properties).

Asbestos board is most frequently used in making induction heating fixtures because it is comparatively cheap, durable, and easy to work with. It can be obtained in the form of sheets in thicknesses varying from 1/8 inch to 2 inches, and it can be machined to very accurate length and width dimensions—despite the fact that it is an abrasive which tends to dull delicate cutting tools.

Where oil is used for quenching, the asbestos board should be protected by two or three coats of paint or shellac. If extremely durable wearing surfaces are required, appropriate areas of the tool may be covered by thin brass plates.

Bending Fixtures

Sections of metal tubing are usually bent into required shapes by means of bending brakes. When it is necessary to produce a large number of identical tubing parts, this work can be most efficiently accomplished by means of *bending fixtures*.

As illustrated in Fig. 131, the essential members of a bending fixture are two form blocks whose working faces are grooved in accordance with the desired shape of the tubing. One of the blocks is firmly attached to a stationary base, while the other is hinged so that it can

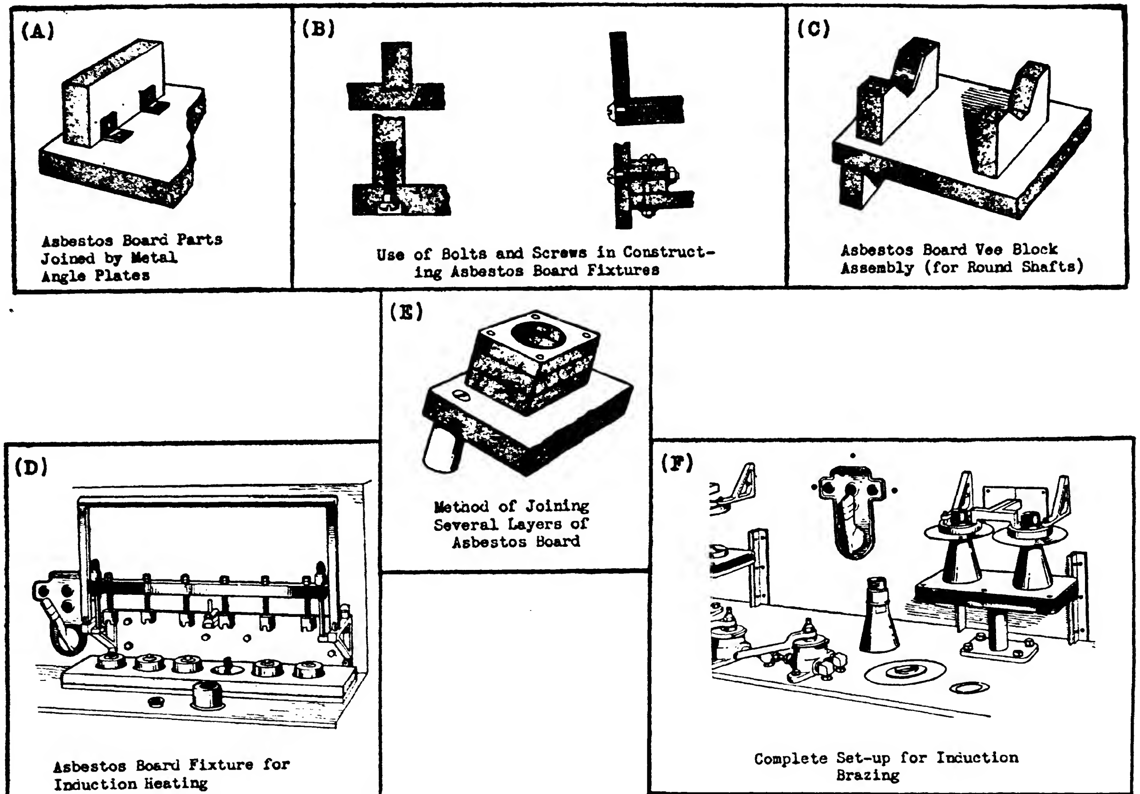


FIG. 130. Built-up Asbestos Board Fixtures. (A) Asbestos board parts joined by metal angle plates. (B) Use of bolts and screws in constructing asbestos board fixtures. (C) Asbestos board vee block assembly (for round shafts). (D) Asbestos board fixtures for induction heating. (E) Method of joining several layers of asbestos board. (F) Complete setup for induction brazing.

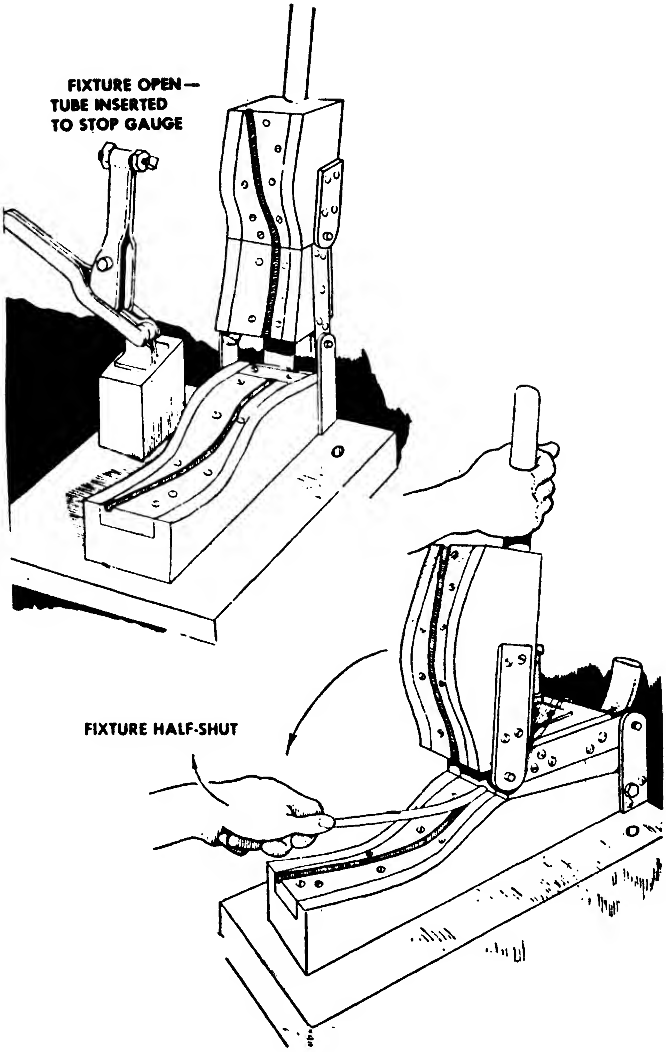


FIG. 131. Bending Fixture.

be moved through an angle of 90 degrees by means of a projecting handle.

The tool is loaded by placing one end of a section of tubing against a vertical wall or stop, which is situated in the rear end of the groove in the stationary form block. Then the tubing is bent by moving the hinged form block until its working face is in the closed position. A clamping device near the tool can be used to apply final pressure, if necessary.

Bending fixtures are particularly useful when two or more bends must be made in single sections of tubing, because they eliminate the multiple operations that would otherwise be necessary. If only one bend is required, the bending fixture serves primarily as a foolproofing device which will prevent many of the mistakes that can be made when an unskilled or careless worker uses a bending brake.

In designing bending fixtures, it is particularly important to allow for the spring back of the metal tubing which must be bent. The necessary form blocks can be readily fabricated by casting either metals or high-strength plastics in suitable plaster molds.

Drill Jig for Drill Press

When operations such as reaming and countersinking are necessary, it is extremely difficult to do accurate work with an ordinary drill press because it is hard to align a reamer or similar tool with the center of a previously drilled hole. Therefore, several manufacturers have equipped their drill presses with jigs similar to the tool illustrated in Fig. 132.

This drill jig comprises a circular band of steel in which bushed holes of various sizes are appropriately positioned. It is mounted on two

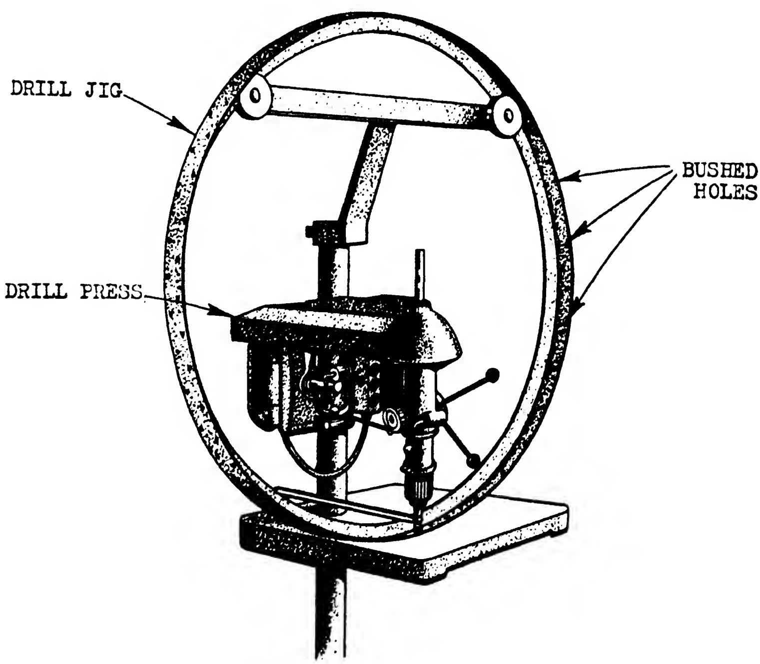


FIG. 132. Drill Jig for Drill Press.

rollers, which are supported at a suitable distance above the drill press by a T-shaped superstructure.

The roller mountings enable the drill-press operator to rotate the jig until a bushing of the correct size is in line with the reamer or countersinking tool. Then it is a simple matter to align the hole in the work with the bushing, and to accomplish an accurate job of reaming or countersinking.

Letters or numbers enable the drill-press operator to identify the bushed holes on the jig in a minimum amount of time.

Model Jigs and Fixtures

Some of the larger jigs and fixtures cost thousands of dollars. If one of these happens to be constructed in accordance with an unsatisfactory tool design, considerable time and money will be wasted. Accordingly, some manufacturers now make it a practice to build small-scale models before finally approving the designs for their more expensive tools.

Two of these models are shown in Figs. 133 and 134. They are built up by gluing together suitable sections of balsa wood and cardboard.

Scale-size human figures are placed alongside the models in order to determine whether the proposed tools will be satisfactory from the

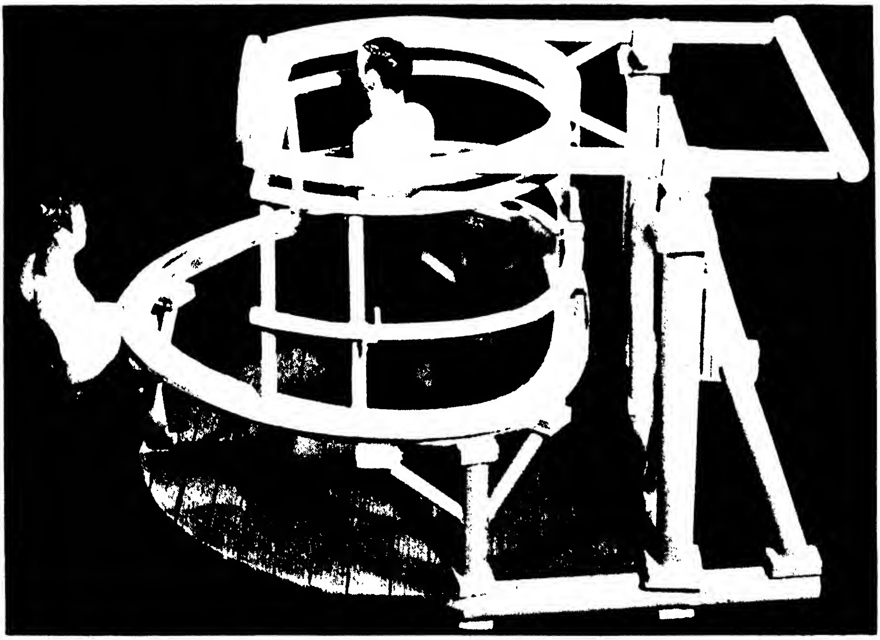


Fig. 133. Model Jig.

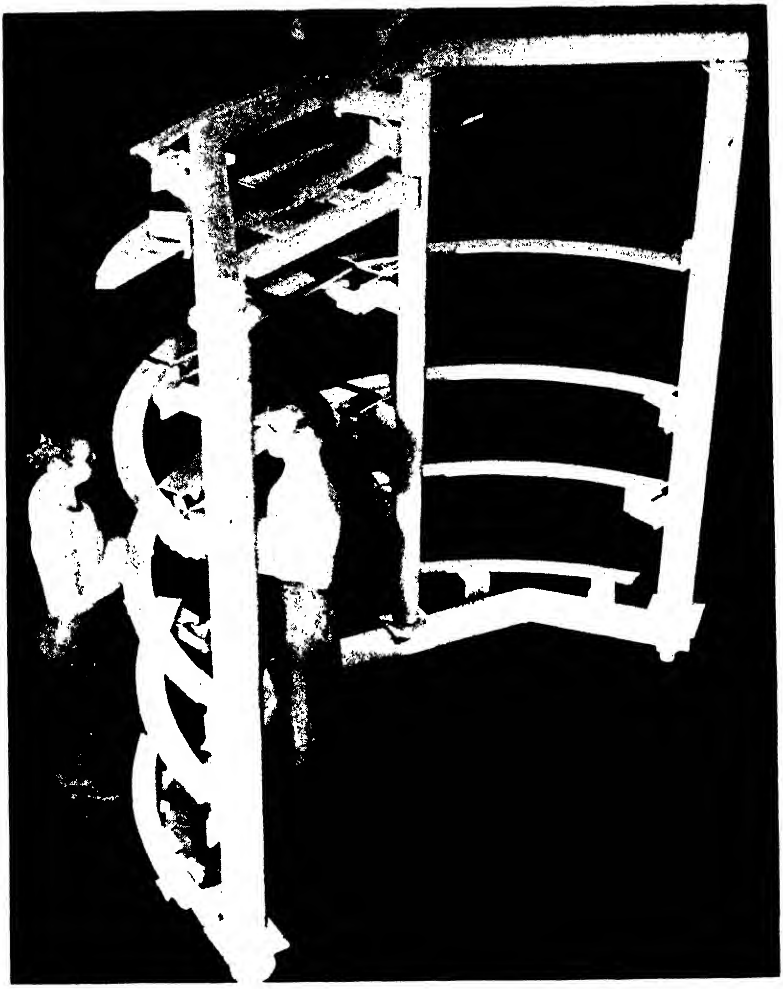


Fig. 134. Model Fixture.

standpoint of accessibility, and both engineering and production personnel are invited to criticize the designs.

This may sound like an expensive undertaking, but the truth of the matter is that hundreds of wood-and-cardboard models can be constructed for less than the cost of one bad assembly jig. Therefore, the models do not have to reveal many design discrepancies in order to pay for themselves.

A good model-maker, if given the proper equipment, can produce individual tools of the types indicated here in a period of four to eight hours and at a cost of only a few dollars each.

Varnishing Fixture

A number of holding fixtures have been developed to facilitate the dip painting of various items of work; but insofar as the authors have been able to determine, there is only one brush-painting fixture, illustrated in Fig. 135.

Built from scrap materials, this fixture is used to varnish flexible fairing strips. It comprises a trough in which a ventilated rubber tube and a series of four paint brushes have been suitably positioned.

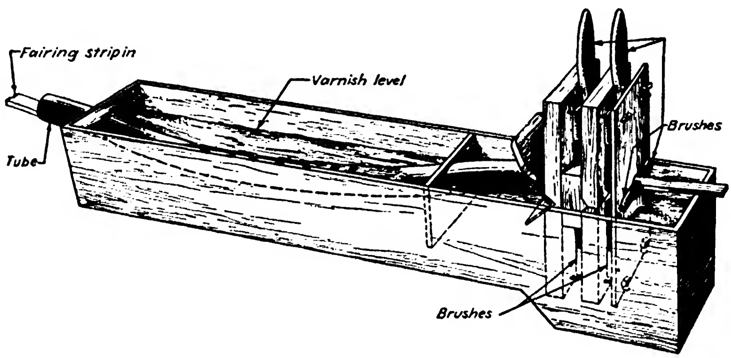


FIG. 135. Varnishing Fixture.

In use, the trough is filled with varnish; then the fairing strips are pushed through the rubber tube so that they will be immersed in the varnish and passed between the bristles of the paint brushes.

Because the paint brushes remove excess varnish from the strips, the fixture conserves materials and produces a smooth finish on the fairing strips. Its speed depends on how fast a man can push fairing strips through the rubber tube.

Scribing Jig

Carpenters have a number of devices for scribing the outlines of circular wooden parts, and one of the most accurate of these is the *scribing jig* shown in Fig. 136.

This jig is simply a round wooden table with one end of a telescoping scribing arm pivotally mounted at its center. A marking arm is attached to the free end of the scribing arm, and it can be extended or retracted so that it will outline any arc of any dimension within the limits of the table top.

An ordinary rule may be used to gage the radius of the circle or arc which is to be scribed, and the scribing arm can be set accordingly by tightening a screw which controls its telescoping joint.

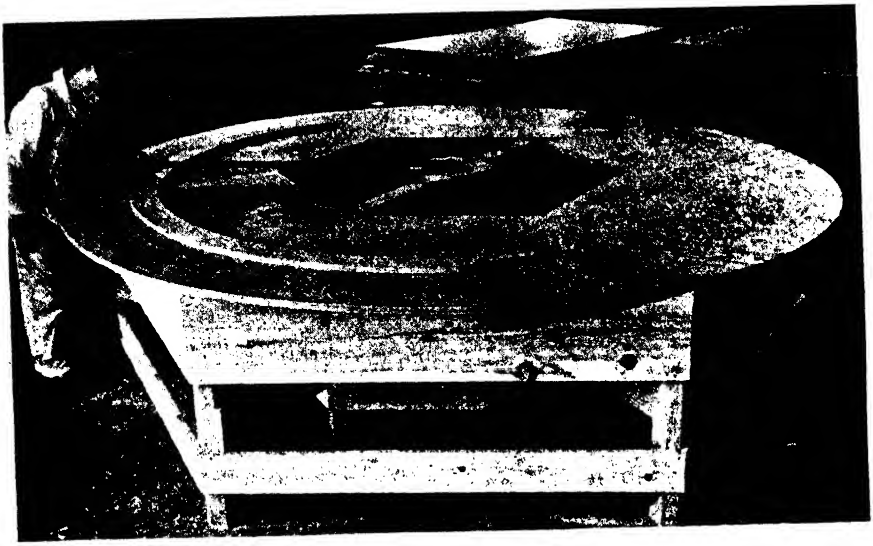


FIG. 136. Scribing Jig.

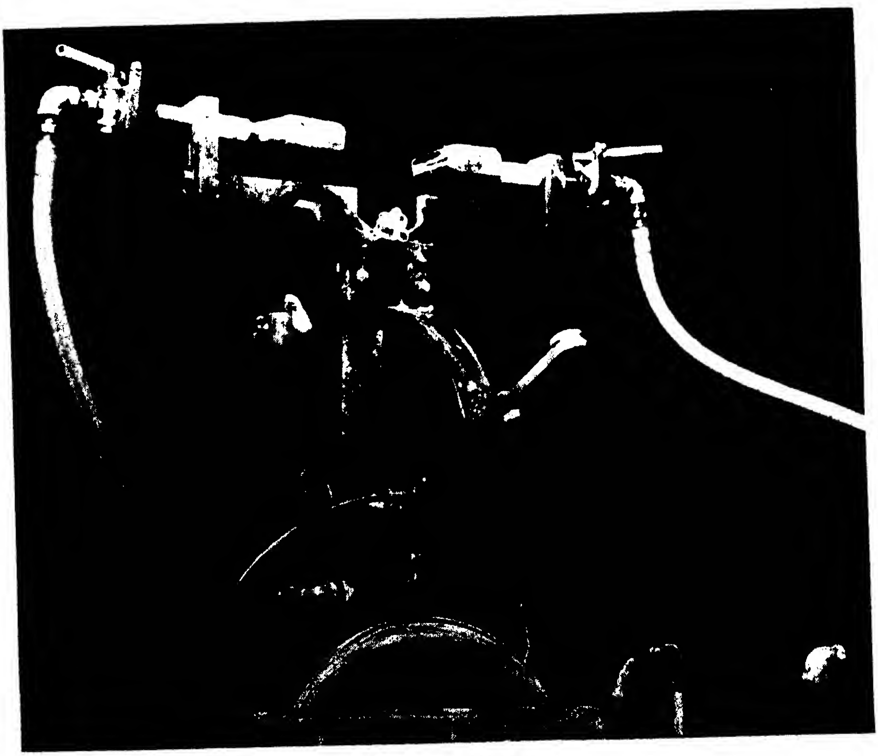


FIG. 137. Brazing Fixture.

Brazing Fixture

Fig. 137 shows an unusual fixture which can be rotated around three different axes for use in brazing engine ignition parts. Before this tool was developed, it was impossible to produce the subject parts with maximum efficiency because it was necessary to braze a number of fittings on each unit separately.

The function of the brazing fixture is to hold a series of brazing torches. Since its mechanism allows it to be rotated around three different axes, it can be readily adjusted to all of the required positions simultaneously.

Besides increasing production, tools of this type improve workmanship by reducing the amount of manual energy that must be exerted by their operators.

Turret-type Drill Jig

A turret-type drill jig, which increases the accuracy with which holes can be made in tubes or rods, is shown in Fig. 138. Essentially, it is a rotary indexing mechanism attached to a metal body or back plate, which is mounted on an adjustable base so that it can be set up on the bed of a single-spindle drill press.

The work is inserted through a hole in the center of the indexing mechanism. When it has been properly located by means of a stop, it can be accurately drilled through a suitable bushing.

The necessary drill bushings are spaced as required in jaw plates held with headless set screws to the jaws of a universal chuck. The

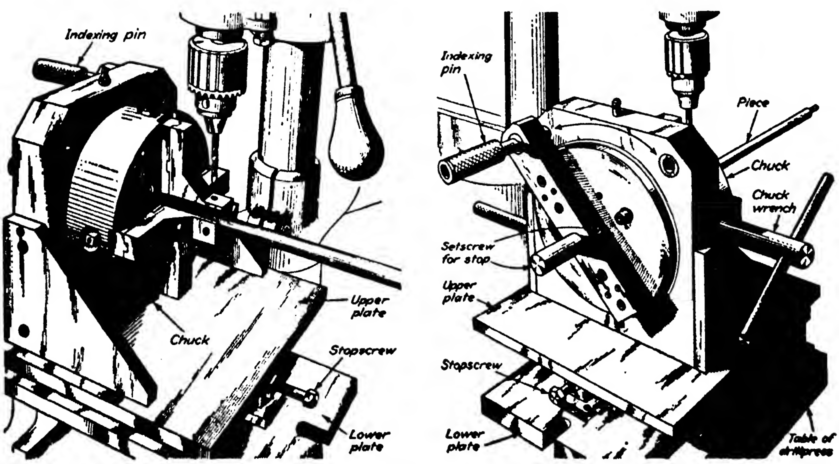


FIG. 138. Turret-type Drill Jig.

chuck rotates in the back plate, and is operated by means of an arm with a spring-controlled indexing pin which can be mated with holes in the back plate.

Stretching Fixture

Manually inserting electrical wires into preformed insulating tubing is one of the most tedious jobs that can be assigned to a worker in any factory. Therefore, a manufacturer of camera equipment has found it possible to increase production and reduce labor costs by developing a

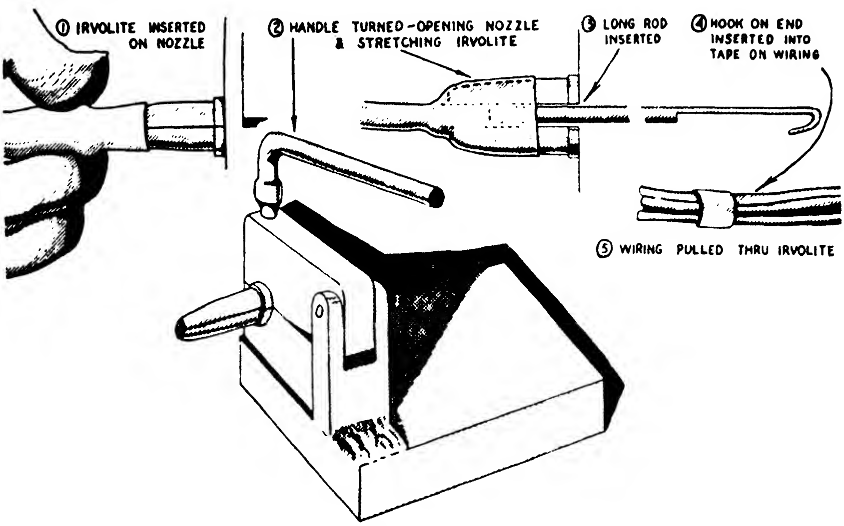


FIG. 139. Stretching Fixture.

stretching fixture which eliminates much of the manual effort required for this type of work.

Details of the stretching fixture are shown in Fig. 139. The purpose of the tool is to spread the lips of a section of rubber tubing, so that wiring may be inserted with considerable ease.

The fixture base is 3½ inches square, and can be clamped to a work table by means of a C clamp. On the base are two vise jaws, each of which supports a half section of tapered metal tubing. The lower jaw is secured to the base, but the upper jaw is hinged and may be moved up or down by means of a screw which is provided with a handle for easy operation.

When a section of rubber tubing is fitted over the half sections of tapered metal tubing, the upper vise jaw is adjusted upward so that the

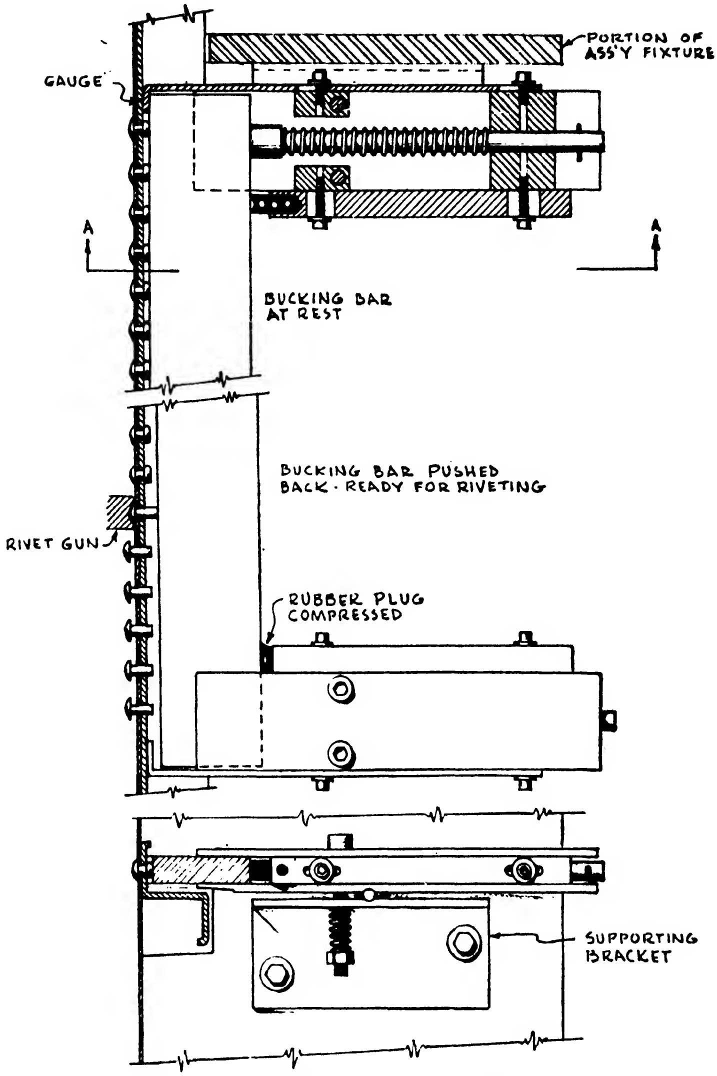


FIG. 140. Rivet Bucking Mechanism.

rubber tubing will be stretched in two directions from the inside. Then a slender metal rod is passed through the insulating tube.

A hook on the rear end of the rod makes it possible to attach the rod to a piece of tape, which has been wrapped around the wiring; and this, in turn, enables the worker to draw the wiring through the stretching fixture jaws and into the rubber insulating tube.

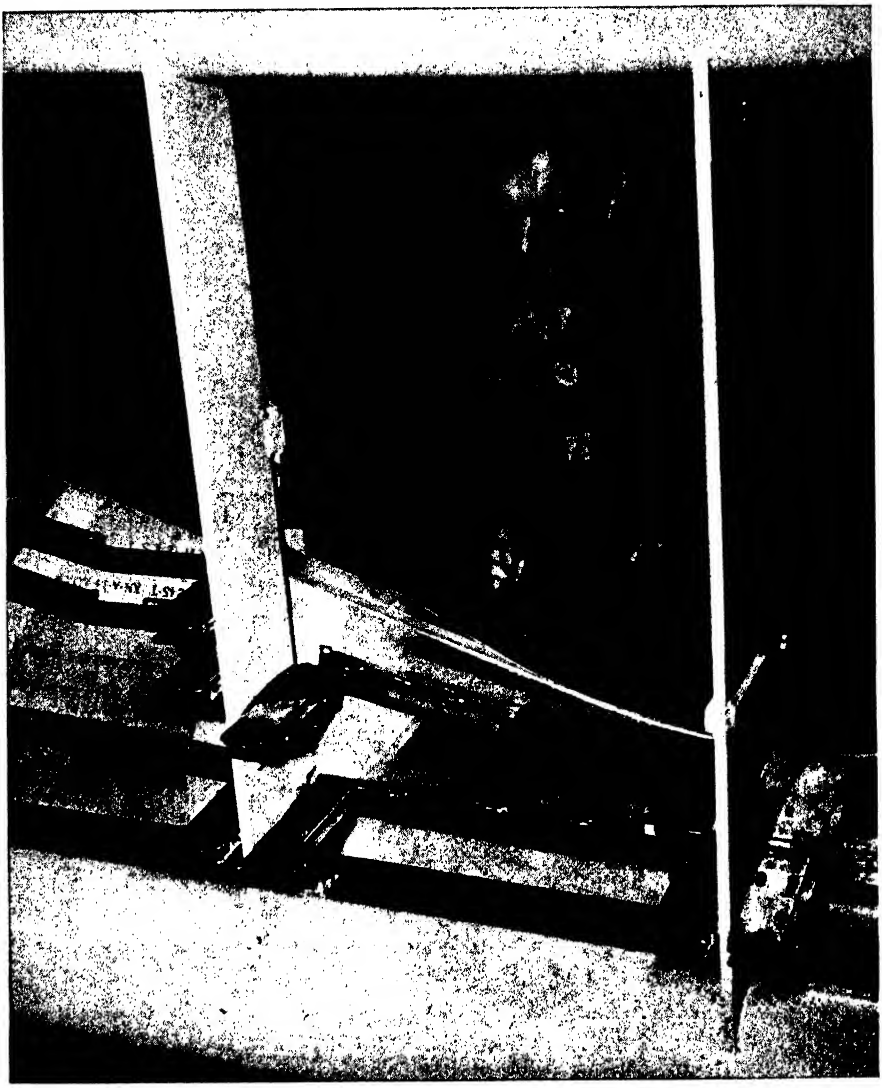


FIG. 141. Rivet Bucking Assembly Jig.

Rivet-bucking Assembly Jigs

By means of the mechanism illustrated in Fig. 140, manufacturers can now construct assembly jigs which will automatically buck rivets. Primarily, the mechanism comprises a *floating* steel bar and two or more spring-actuated reacting hammers.

As indicated in Fig. 141, the floating bar may be shaped in conformity with the configuration of any row of rivets. It is supported at

each end by a device pivotally mounted to the framework of the jig and housing the reacting hammers.

When a rivet is inserted in the assembly held by the jig, its shank immediately contacts the floating bar. Consequently, rivet-gun impulses are transmitted through the rivet and the bar to the reacting hammers, which set up opposing forces to hold the bar in place. Specially formed rubber stops, one of which is adjacent to each of the reacting hammers, damp any tendency of the bar to vibrate; and the hammers can be set by means of gaging devices so that they will cease to react, and thus change the sound of the riveting, as soon as the rivet shank has been properly formed.

The advantages of having assembly jigs which automatically buck rivets might be listed as follows:

(1) They reduce time and man-power requirements by approximately 50 per cent.

(2) By eliminating half of the rivet team, they also eliminate most of the mistakes that can be caused by poor teamwork.

(3) They enable riveters to accomplish exceedingly uniform work.

(4) They do not necessitate the use of highly skilled workmen.

(5) Their cost is less than that of ordinary squeeze-riveting equipment.

However, it should be realized that rivet-bucking jigs are strictly mass-production tools and could not be profitably used in connection with small-scale manufacturing.

Stamping Fixture

In factories where high standards of craftsmanship prevail, it is necessary to inspect each part with extreme care. If the part passes the inspection, it must be carefully stamped so that it cannot possibly be mistaken for a part that has not been inspected. This can usually be accomplished without special equipment; but if the part happens to be small and carefully dimensioned, serious damage might be caused by the stamping process. Therefore, a number of manufacturers are now making use of *stamping fixtures*.

A typical stamping fixture is shown in Fig. 142. It is simply a wooden block, end-supported a slight distance above the surface of a workbench, and its function is to provide a base upon which the prongs of carefully dimensioned metal forks can be positioned. As many as ten forks can be placed on the fixture at one time.

Besides preventing damage, stamping fixtures save considerable time and free inspectors from the fear of making mistakes.

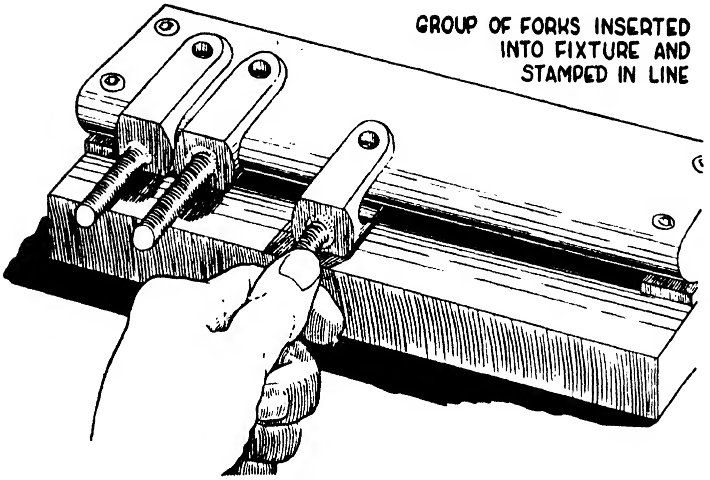


FIG. 142. Stamping Fixture.

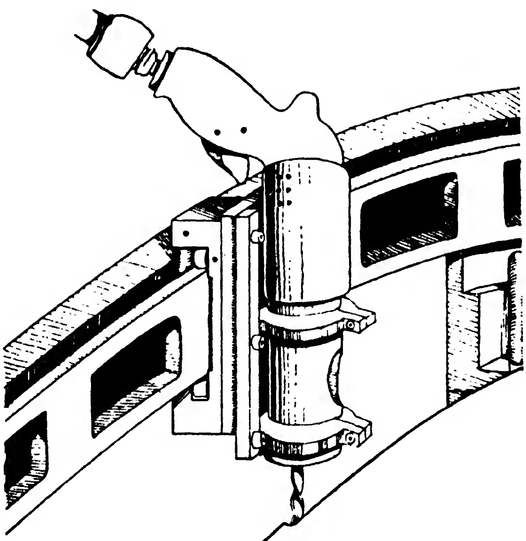


FIG. 143. Routing Jig.

Routing Jig

Because it is sometimes necessary to trim the edges of formed metal parts prior to assembly, cutting tools such as the router must occasionally be used. If the edge tolerances are close, special *routing jigs* may also be required.

Fig. 143 shows a typical routing jig. It is simply a metal rail, designed to guide and support a router in a suitable attitude alongside the metal part which is to be trimmed.

Since they usually have only one critical dimension and since they can be constructed in accordance with the lines on parts templates, routing jigs are fairly easy to design, although it is a common mistake to make them too large.

Routing jigs are generally subject to considerable handling. If they are large and heavy, much time may be lost in moving them from place to place. Therefore, when it is necessary to trim large parts, it is often best to break down the large tool design so that two or more small routing jigs may be utilized for each job.

Automatic Riveting Fixtures

The efficiency of automatic riveting machines has been greatly increased in a number of factories by the use of special combination fixtures, such as the specimen illustrated in Fig. 144. These tools have two major functions:

(1) They hold in proper relationship to one another the parts that are to be assembled.

(2) They locate the points at which holes are punched and rivets are driven.

Automatic riveting fixtures do not have to be designed, because they can be fabricated directly from the layouts of the parts that are to be assembled. They should always be made from light-weight materials, such as plywood and aluminum-alloy sheet, so that they can be easily manipulated by machine operators.

The following procedure has been adopted by one large manufacturer for the construction of automatic riveting fixtures from sheets of ⅛-inch-thick 24-ST dural:

(1) The master layout for the parts to be assembled is reproduced on the dural sheet.

(2) The tool is "planned" by the toolmaker at his workbench. The planning consists of studying the layout reproduction and deciding on the best means of installing clamps, stops, bridges, and other units.

(3) The layout reproduction or template is cut to the correct length and width.

(4) The lines layouts for slots are extended by scribing, so that the lines can be checked after the slots are cut in operation No. 10. This is necessary because the heat of the cutting tool will probably eradicate all of the original layout lines in its immediate vicinity.

(5) Filler strips are positioned and riveted to the template. Drilling, counterboring, and countersinking are performed, whenever necessary, as part of this operation.

(6) All rivet locations marked on the template are center punched.

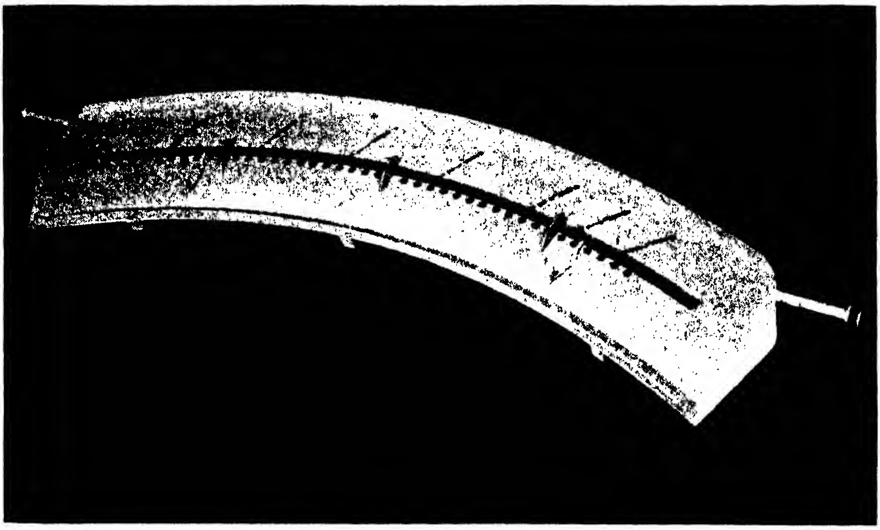


FIG. 144. Combination Fixture for Automatic Riveting.

(7) The rivet pattern is drilled with a tool whose size is the same as that of the pilot in the counterbore, which will be used in the next operation.

(8) The rivet pattern holes are counterbored, so that the dimensions of the drilled holes will be 0.004 inch larger than the diameter of the machine stripper.

(9) The rivet pattern holes are countersunk approximately $\frac{3}{64}$ inch deep, so that the machine stripper can be readily fitted therein.

(10) Slots for the standing legs of angles are cut in the template.

(11) With reference to the lines scribed in operation No. 3, the slots are filed to the correct dimensions.

(12) Drill bushings are installed in all tooling holes.

(13) Drill bushings are installed for the drilling of holes where the

over-all material thickness of overlapping parts exceeds the dimensional limitations of the riveting machine.

(14) Stiffening angles are attached to the template.

(15) Stops are made, fitted, and installed on the template.

(16) Bridges are made, fitted, and installed on the template.

(17) Clamps are made, fitted, and installed on the template.

(18) Legs are installed as necessary.

(19) Two handling arms are installed so that the tool will be perfectly balanced when loaded.

When the tool has been fabricated and loaded, its handling arms are attached to spring-balanced handling fixtures which project from the sides of the riveting machine. Then it is necessary only for the operator to guide the tool and control the machine operations. Fig. 145 shows how each hole in the fixture is positioned over the stripper and beneath the die in the riveting machine. A mirror, attached to the base of the machine and focused on the bottom side of the fixture, enables the operator to guide the fixture so that the proper holes therein can be quickly and easily positioned over the stripper, as indicated in Fig. 146.

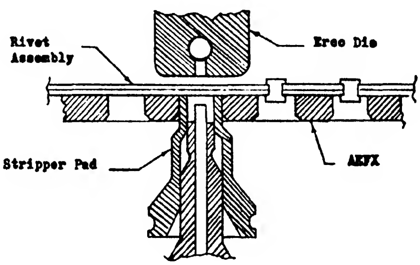


FIG. 145. Combination Fixture Positioned in Riveter. (The abbreviation AEFX denotes the fixture body.)

In designing parts to be assembled by means of automatic riveters, it is particularly important to make sure that the parts' thicknesses do not conflict with the dimensional limitations of the machines. All extrusions, stiffeners, and other items should be on the same side of the web. When stiffeners are used parallel to flanges, they should be on the side opposite to the web so that it will not be necessary to weaken the fixture by cutting parallel slots.

Unless a special die is used on the riveting machine, rivets should not be placed close to a bend radius. Closed flanges should generally be avoided in order to prevent interference with the die and stripper pad. The spacing of rivets should be such that the die will not interfere with an adjacent rivet in the course of any individual operation and such that there will be no overlapping of hole patterns in the indexing fixture. If possible, all of the rivets in the assembly should be of the same size because this will eliminate the necessity of changing the machine setup in the middle of a job.

Caution should be exercised in selecting and using extrusions and

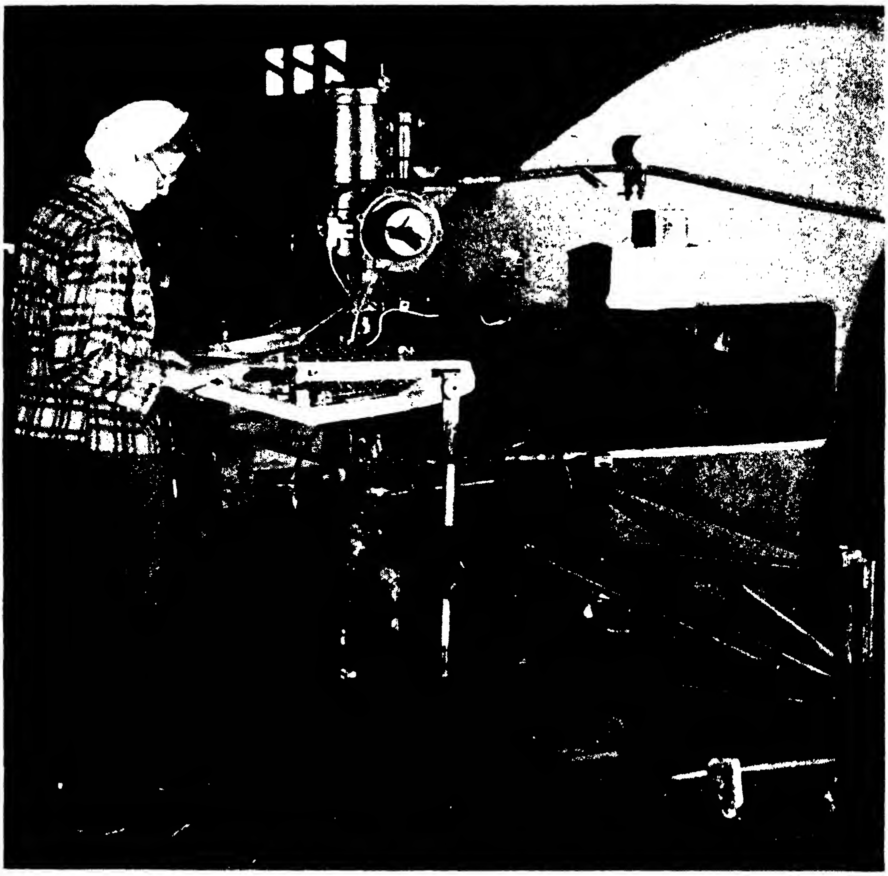


FIG. 146. Automatic Riveting Fixture in Use.

similar formed shapes. Angles with narrow legs, C channels, and bulb angles should be avoided. Z sections should be used whenever possible; and, when hat sections are necessary, it is best to choose those hats with flat contact planes.

Welding Jigs or Fixtures

Welding jigs or fixtures differ from ordinary assembly jigs or fixtures in that the former, besides locating and holding parts, should neither interfere with the thermal expansion and contraction of the components nor absorb too much welding heat. If the parts to be assembled are of heavy metals such as steel, tool interference will cause undesirable stresses to be set up within the assembly. If the components are of light metals such as aluminum, it will cause parts of the assembly to become

FIG. 147. Gas-welding Jig.

warped or buckled. Similarly, if the welding jig or fixture absorbs too much heat, the time required to make the assembly will be increased and even more undesirable physical phenomena may be encountered.

Fig. 147 shows a small welding jig which was specially designed to prevent the buckling of aluminum-alloy parts. Its base is a turntable, on which are an asbestos insulating pad, a steel block, and a hinged holding device. The purpose of the asbestos pad is to keep the turntable from absorbing heat. The steel block is shaped to accommodate the flat section of aluminum-alloy sheet which must be united with a section of aluminum-alloy tubing in the jig, and the holding device is such that it will allow either of the parts to expand in one direction without interference. In use, the steel block is preheated to a temperature of approximately 1000°F. so that it will in turn preheat the flat section which it is to hold; then, when the flat section has been placed on the block, the section of tubing is appropriately positioned by means of a round gate on the end of an internal brace at the top and a screen core at the bottom.

What might be called a universal fixture for arc-welding small steel parts is shown in Fig. 148. Essentially, this tool is a table whose top can be rotated through an angle of 90 degrees so that the work positioned thereon will at all times be accessible to the welder. Its clamping or holding device is a screw-type mechanism supported in a vertical position over the table by an adjustable L-shaped arm. Because the action of this device is one-dimensional, the parts of the assembly to be welded can expand or contract freely.

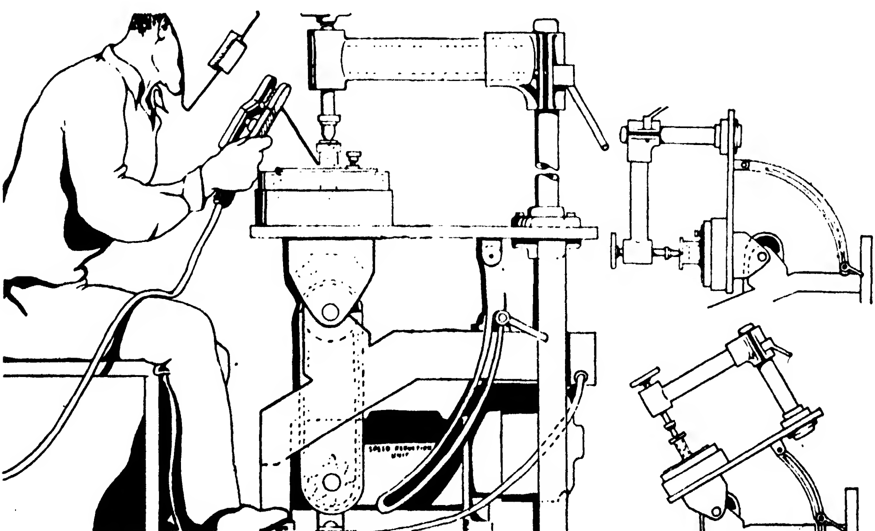


FIG. 148. Universal Arc-welding Fixture.

Jigs and fixtures are not often used in connection with spot-welding operations, because the parts to be united can be located by means of gages and held together by means of simple clamps or fasteners. However, when it becomes necessary to remove the clamps or fasteners in order to eliminate welding electrode obstructions, various types of alignment fixtures may be advantageously utilized. One of these alignment

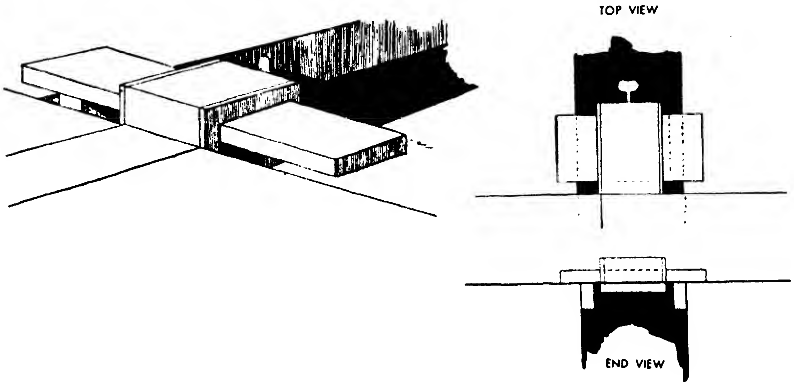


FIG. 149. Alignment Fixture for Spot Welding.

fixtures is indicated in Fig. 149. This fixture is simply a wooden block, held in place over an indexing table slot by means of a rectangular base and two projecting feet. Its function is to square the ends of two flat sections of sheet which are in the process of being spot-welded.

Chamfering Fixture

A large engine manufacturer has found it possible to save considerable time and trouble in machining a flanged hub at the end of a starter and accessory drive shaft by means of the *chamfering fixture* shown in Fig. 150.

This job necessitates the forming of a radius at each end of all of eight cross holes drilled through the hub; and before the chamfering fixture was developed, the outer ends of the holes were chamfered by using a ¾-inch drill and polishing the chamfers to form the radii after the piece was heat-treated. Radii at the inner ends of the holes were formed with an air-driven polishing wheel in a wooden block on a bench.

In the chamfering fixture, the work is clamped in a vee block so that its angular position can be controlled from the side by means of an indexing pin and so that one pair of holes will always be in line with a drill-press spindle which carries a special holder with one fixed cutter to round the edge at the outer end of the upper hole.

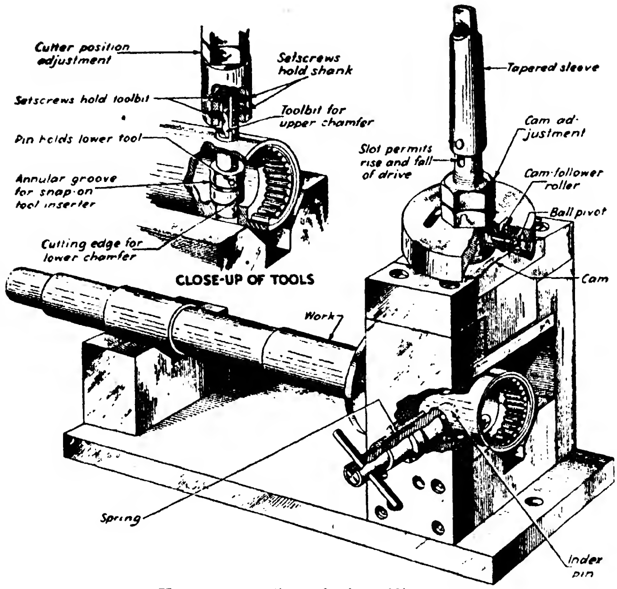


FIG. 150. Chamfering Fixture.

The holder is raised and lowered during each revolution by a cam set into the top face of the fixture, and a flange on the holder carries a pair of rollers that ride on the cam and cause the tool to follow the variations in the height of the hole edge. A hollow cutter, attached to the lower end of the same holder and set inside the hub hole, simultaneously forms a radius on the inner end of the lower hole.

Since the lower cutter is at right angles to the upper cutter, thus corresponding with the similar displacements of the high parts of the hole rims, one inner and one outer hole edge are given the required radii simultaneously at each of the eight indexed positions.

Jig for Drilling and Countersinking

Fig. 151 shows details of a jig in which two keys are positioned and held in camshaft keyways so as to permit the drilling and countersinking of rivet holes in a single operation. The camshaft is represented by the letter *B*, while the rivet holes are designated by the letter *C*.

Yokes *F* are properly spaced by straps *G* and slipped over the assembled camshaft and the two keys, while the jig is positioned by clip lock *H*—the clip of which fits in an oil groove in the camshaft. Then leaf spring *J* is inserted along the top of key *D*, pulling yokes *F* up against key *E* and holding both keys tight in the jig; spring *J* is positioned by spring lock *K*, which also fits in the oil groove.

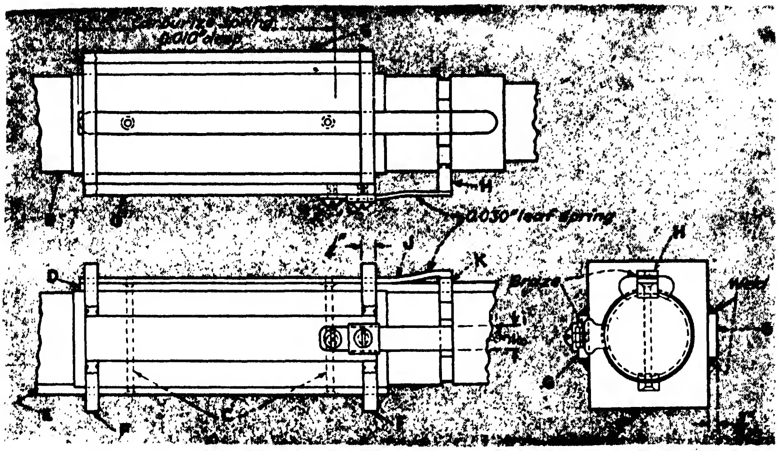


Fig. 151. Jig for Drilling and Countersinking.

When rivet holes have been drilled through leaf spring *J* and the camshaft, the holes in key *E* can be countersunk; then the jig can be reversed and the holes in key *D* can be countersunk. Thereafter, the keys and camshaft are ready for riveting.

Locating Fixture

In a factory where machine guns are assembled, it was recently found that considerable time was being lost in the process of positioning and fastening steel balls on gun-charger cables. The worker had to insert a cable in a gun-charger arm, fasten it to a gun-charger plunger, move the ball to the proper location on the cable, tighten the set screw which held the ball in place, and then put the assembly in a vise so that the set screw could be run down and staked.

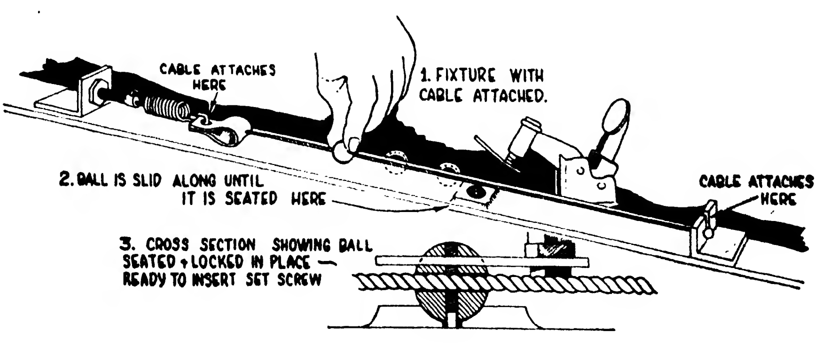


Fig. 152. Locating Fixture.

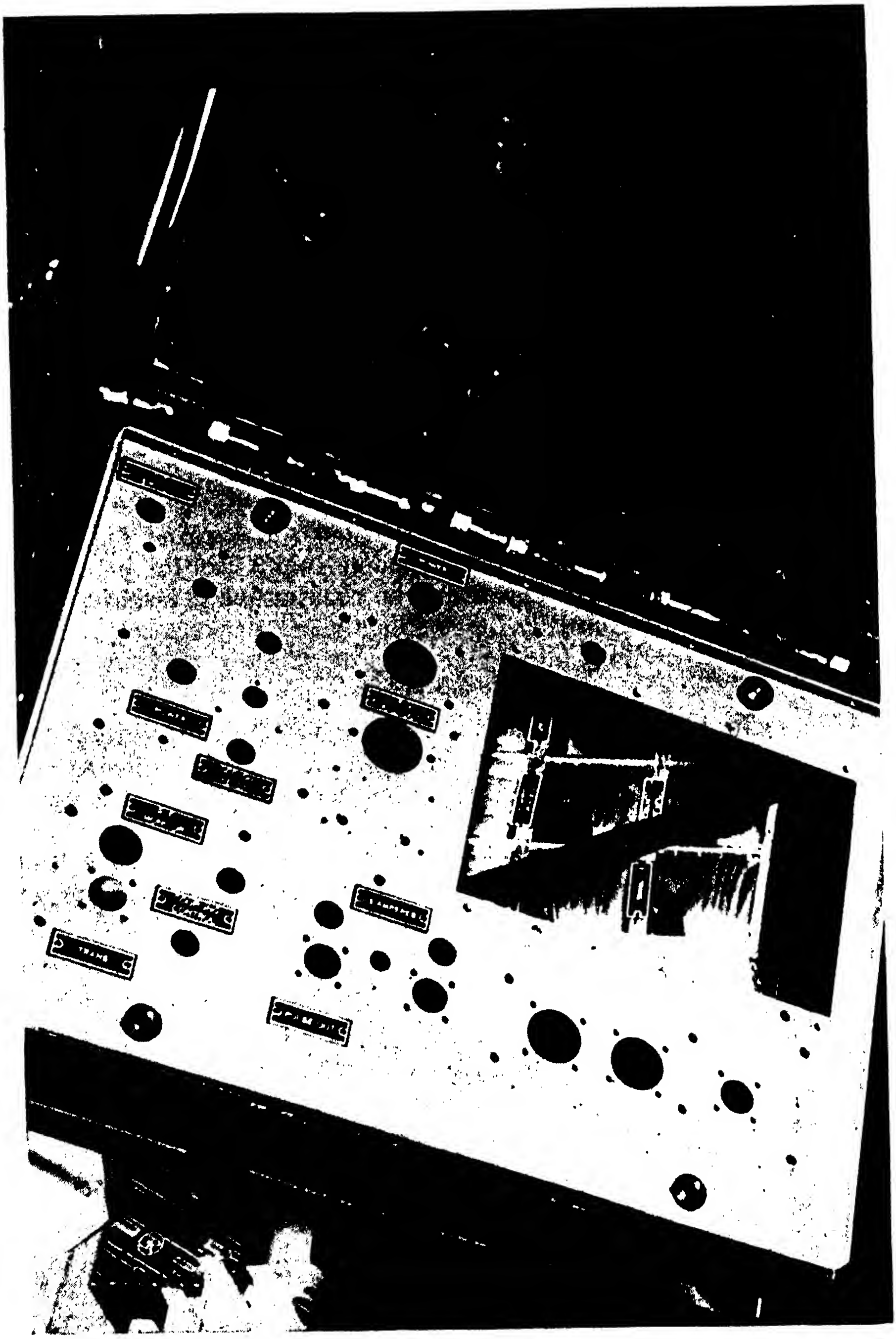


FIG. 153. Name-plate Attachment Jig.

Obviously, this was a tedious job; and, furthermore, an investigation revealed that the workers were suffering occasional injuries due to screwdriver slippage in the process of tightening the set screws. Therefore, the fixture shown in Fig. 152 was developed.

With this fixture it is possible to secure and stake the steel ball to the gun-charger cable before the cable is installed in the charger arm. A clamp holds the ball in the correct position, and it has an opening which enables the operator to insert and stake the set screw.

As indicated, the fixture is simply a metal strip with two angles, which are positioned so that the charger cable can be tautly attached to them, and an indented metal seat, which locates the steel ball. This metal seat is positioned on a workbench alongside the clamp, which holds the ball in place.

Name-plate Attachment Jig

Fig. 153 shows an unusual jig which has been used in attaching name plates to the panels of radio transmitters. It comprises a rectangular frame, to which the individual transmitter panels can be separately attached, and three hardened anvils, which are hinged to the frame.

When a panel has been suitably positioned in the rectangular frame, the required name plates are located over predrilled holes in the panel and held in place by inserting rivets in the holes. Then the hardened anvils are rotated until they contact the face of the panel.

The anvils are locked in the latter position by means of latches on the jig frame, and the jig is turned over so that the undriven rivet shanks will be exposed. Thereafter, it is a simple matter to drive the rivets which hold the name plates, with a conventional pneumatic rivet gun.

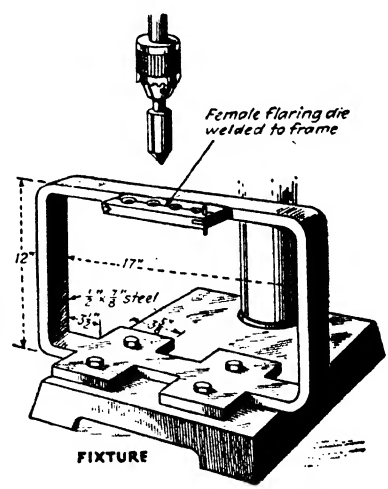


Fig. 154. Tube-flaring Fixture.

Tube-flaring Fixture

Metal tube flaring is a comparatively simple operation, if adequate holding tools are provided. Therefore many manufacturers have found it expedient to develop *flaring fixtures*.

One of these is the tool shown in Fig. 154. It is used in flaring copper tubes with diameters ranging from $\frac{3}{16}$ to $\frac{5}{8}$ inch.

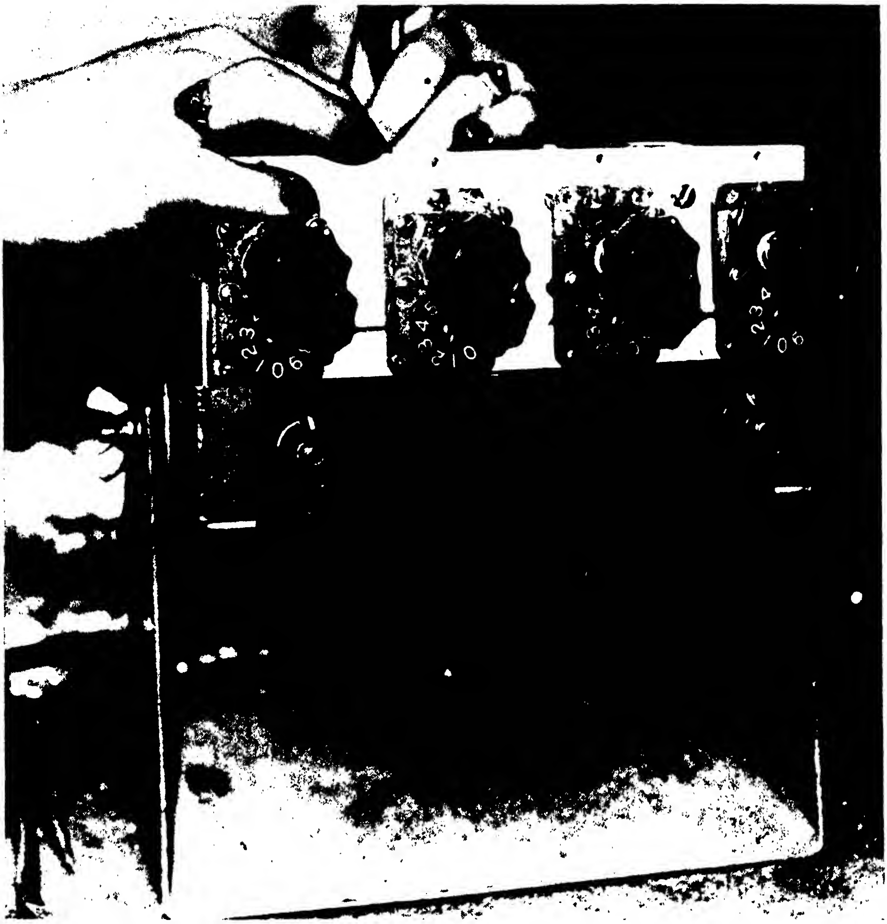


FIG. 155. Universal Assembly Jig.

The main portion of the fixture body is a ½″ by ⅞″ strip of steel bent into a rectangular shape and attached with bolts to a suitable base. Welded to the upper portion of this body is a split female flaring die.

The tubing to be flared is vertically clamped within the flaring die, and then the flaring is accomplished by lowering a two-bladed flaring spinner (which may be actuated by the motor of a conventional drill press) into the mouth of each section of the tubing.

Universal Assembly Jig

A small sheet-metal assembly jig, which can be adapted for use in connection with a variety of jobs, is shown in Fig. 155. It comprises a simple chassis mounted on a U-shaped metal stand.

Two wing nuts and bolts on the side of the jig enable workers to rotate the chassis to any position required for maximum accessibility, while two wing nuts and bolts in the front portion of the chassis are used to fasten the work in place.

When it has been properly positioned, the chassis is firmly held by means of a spring pin in an indexing plate and the stand is attached to the tracks of a mechanized assembly table. Then, as the jig is moved along the assembly table, workers install small parts on the sheet-metal panel which it supports.

Jigs of this type cost about two dollars each. If necessary, they can be made from scrap materials.

Gear-checking Fixture

In checking small gears for accuracy, it is customary to use wire and micrometer gages. In one large factory considerable inspection time has been saved by using the fixture shown in Fig. 156 for such work. With a single setting of its mechanism, the fixture checks the following items on innumerable gears of a given size:

(1) Runout of pitch diameter.
(2) Concentricity of bore with pitch diameter.
(3) Size of gear bore.
(4) Faulty teeth.
(5) Excessive burrs.

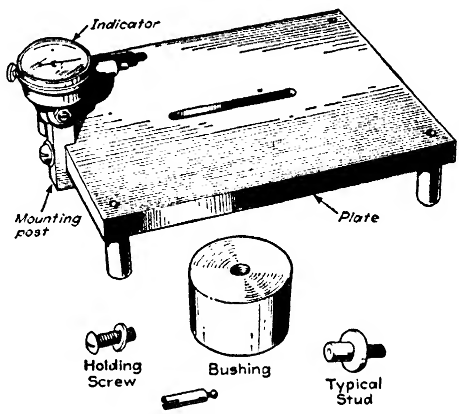


FIG. 156. Gear-checking Fixture.

The body of the tool is a square mounting plate, which is made from cold-rolled steel by cutting a ¼″ by 2½″ slot in its center and attaching suitable legs or feet to its corners. Affixed to the end of this plate and keyed into position by a screw and washer is a slotted mounting post on which a dial indicator is mounted in a horizontal position, parallel to the plate, so that its measuring arm is aligned with the slot in the body. Other equipment includes a bushing, a set of hardened studs whose sizes correspond with the gear bores for the purpose of positioning the gear to be checked, and a set of hardened balls whose sizes correspond with various wire diameters.

The following steps are necessary in using the gear-checking fixture:

(1) The pitch diameter of the gear is determined by conventional methods, and one half of this measurement (less one wire diameter) is determined so that the identical distance may be set up between the adjustable stud and the ball on the indicator arm by means of Johansson blocks. The settings are made from the diameter of the stud to the end of the indicator ball.

(2) Adjustment screws are tightened, and the indicator is set at zero.

(3) Gears are placed one at a time on the hardened stud and checked by means of the indicator.

The diameter of the hardened stud must, of course, be within the tolerance limit of the gear bore for the gears being inspected.

Plastic Tool Masters

A large East-coast aircraft manufacturer has found it possible to maintain unusually close assembly-jig tolerances by fabricating plastic tool masters to serve as inspection fixtures. The masters are produced by casting Catavar 101 (a moldable thermosetting plastic with low-

FIG. 157. Making the Female Plaster Shell or Mold.

shrinkage and high-stretch physical properties) in accordance with the following procedure:

(1) Templates from the lofting department are enlarged slightly to allow for the shrinkage of the plastic in curing.

(2) A male plaster shell is produced by setting the templates in suitable positions, building a burlap-and-wire netting frame 2 inches below the template outlines, and applying patternmaker's plaster thereto. While it is still soft, the plaster is contoured or "splined" by means of a straightedge or a section of piano wire; then, when the plaster is dry, the shell is sprayed with a black rubber paint, which serves as a parting agent and prevents moisture absorption when the female cast is made.

(3) A reinforced female plaster shell or mold is made by applying a splash coat of plaster to the male plaster shell and reinforcing the coat with matted sisal fiber dipped in plaster. (*See* Fig. 157.) The female pattern must be reinforced because it is expected to hold a considerable volume of plastic without being cracked or distorted. Steel bars can be

Fig. 158. Pouring Preheated Plastic in Mold.

Fig. 159. Plastic Tool Master.

placed longitudinally about 10 inches from the shell and connected to the shell by plaster legs (which are made by dipping sisal fiber in plaster), to avoid warpage due to unequal expansion. Also, warpage can be prevented by leaving the ends of the mold open, connected only by hook bolts and turnbuckles, until the plaster is thoroughly set.

(4) When the male and female patterns have been separated, the mold cavity is coated first with zinc-chromate primer and then sprayed with black and white rubber paints.

(5) The plaster mold is dried for a period of two or three days in an air-circulated oven at temperatures of 100°F. to 150°F., to prevent cracking.

(6) Approximately 12 hours before the end of the drying cycle, drums of Catavar are placed in the oven to reduce the time required to set after the plastic is poured into the mold. This heating causes the plastic to become a heavy "syrup."

(7) When it is taken from the oven, the mold receives two coatings of wax, which serve as a parting agent for its casting surfaces.

(8) End plates are applied to the mold, as necessary.

(9) The preheated plastic is poured into the mold (as indicated in Fig. 158), and the mold is returned to the oven.

(10) When the temperature of the oven is at 150°F., the timing cycle begins and continues for 72 hours.

(11) The mold and its casting are allowed to cool to room temperature. (*Note:* The casting might warp slightly if removed from the mold before it has been adequately cooled.)

(12) The casting is removed from the mold, and holes are drilled through its web so that lifting eyes can be attached thereto.

(13) The casting is set up on a surface plate so that its base line can be scribed.

(14) One end of the casting is planed square with the base line. Then the casting is set up on a surface plate and the other end is indicated with a height gage.

(15) After the second end of the casting is planed, station templates are fastened to the machined ends of the casting; and the contours of the plastic plug are scraped in accordance with the markings made by a

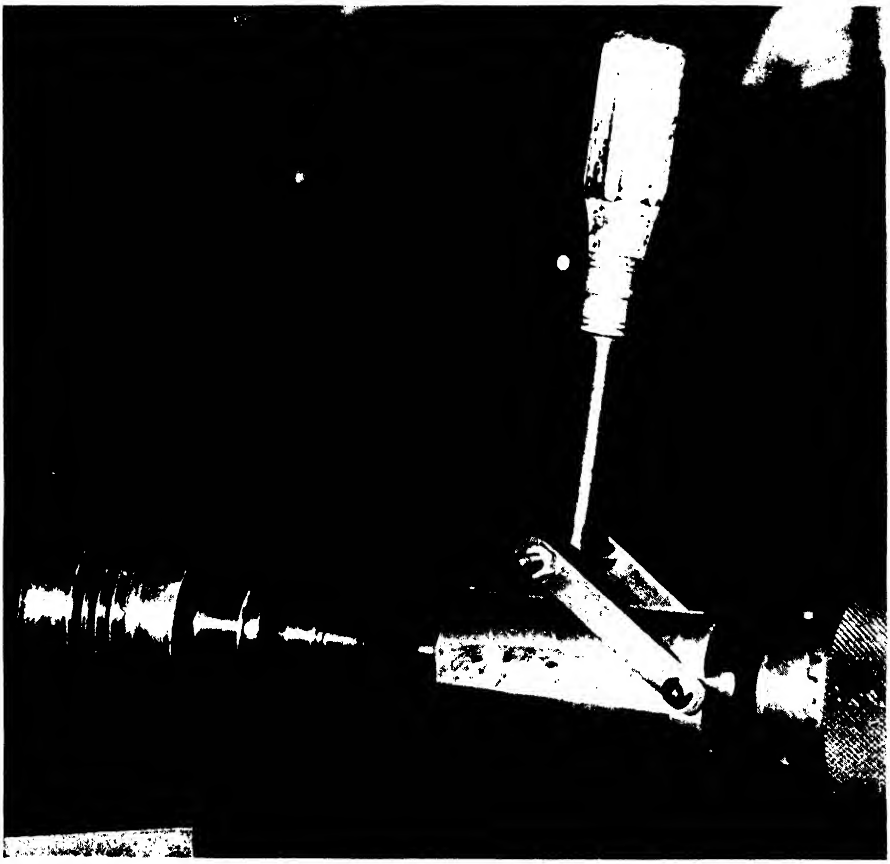


FIG. 160. Lathe Fixture.

straightedge, which is held against the station templates in order to transfer color to the high spots on the casting. Power hacksaw blades are generally used for the scraping.

(16) The scraped surfaces are buffed with a suitable compound.

Fig. 159 shows a plastic tool master which was thus fabricated, as it is used to check the assembly jig for the leading edge of an airplane wing. Tools of this type are extremely useful in mass production, because they are cheap and because they will retain close dimensions far better than tools made from other materials—provided they are not subjected to extremely rough handling.

Lathe Fixture

A very simple lathe fixture, which can be used to press a Bakelite bushing and a silver sleeve onto a brass stud, is shown in Fig. 160. It has a cylindrical steel body attached to a lever so that it can be manually moved fore and aft, after it is set in the "tail stock" of a bench lathe.

First, a stud is pressed into the collet in the lathe spindle and a Bakelite bushing is fitted into the adapter in the fixture. Then the fixture lever is pulled back so that the bushing will be pressed onto the stud.

The silver sleeve also fits into the fixture adapter, and can likewise be pressed onto the stud by pulling back on the fixture handle.

GLOSSARY

ABRASIVE. A material which has a marked tendency to cause wear when rubbed against another material.

ABUTMENT. A projecting part, or a part which is used to locate or unite a member of a structure.

ACCESSIBILITY. The quality of being approachable or within the reach of a workman.

ADAPTER PLATE. An attachment which enables a tool or machine to hold or support a unit whose design would normally make such a union impractical.

AGING (of metals). The process of allowing metals to attain full hardness, following a heat treatment, by leaving them inert at room temperatures for various periods of time. If extraneous heat of any kind is used, the process is called *artificial aging*. Otherwise, it may be aptly termed *natural aging*.

AIRFRAME. Either the fuselage of an airplane, or an entire airplane structure minus the power plant and its controls.

ALLOY. Usually a combination of metals, or the act of combining metals.

ALLOYING ELEMENT. A substance used in making an alloy.

ANALYSIS. The act of separating or resolving into constituent parts or elements.

ANNEALED. A condition caused by a heat treatment whose purpose is to soften, refine, or relieve internal stresses in metals. The annealing process consists of heating the metals above their critical ranges, or to their solid solution temperatures, and allowing them to cool slowly.

ANVIL. Usually an iron block with a smooth face of steel; or, figuratively, anything upon which blows are laid.

ASBESTOS. A fibrous material which is incombustible.

AUTOMATIC RIVETER. A machine which will punch holes and drive rivets in an assembly.

AXIS. A reference line (usually imaginary) around which a body revolves or tends to revolve. It is considered to represent the centers of all the cross sections of a body (*pl.* AXES).

BABBITT. An alloy metal with a low friction coefficient, often used for bearing linings. There are several types of babbitt, each with a tin base and various combinations of arsenic, copper, antimony, and lead as alloying elements.

BAKELITE. The trade name of a group of plastics.

BEAM. A structural member or section, designed to absorb and transmit the loads acting on various parts of a structure.

BEARING STRENGTH. The strength with which a member of a structure is able to resist stresses created when loaded parts of the structure press or bear against that member.

BILLET. A metal bar, reduced from a cast ingot by rolling or hot forging.

BLEED. To withdraw fluid from a hydraulic system so as to eliminate air locks.

BORE. The inside diameter of a cylinder, tube, or hole; or the act of removing material with a boring tool.

BOSS. A stud, knob, or protuberant part; or a die used for stamping metals into shape; or the enlarged part of a shaft or a hub at the point where a joining is made; or a thick section in a casting, designed to support threads, to provide a bearing area, or to facilitate machining operations.

BRACE. That which holds anything tightly; or a reinforcing member of a structure; or a manually operated crank which is used in drilling holes, driving screws, and so forth.

BRACKET. An angular stay used to support shelves, scaffolds, or other items; or a tie for strengthening angles; or a projection for carrying shafting.

BRAZING. The act of soldering or uniting metals with a molten brass alloy.

BRIDGE. A structural member which joins two parts.

BROACH. A precision tool with cutting teeth that works on the principle of a file.

"BUGS." Flaws or discrepancies.

BURR. A slight ridge of metal caused by drilling or otherwise cutting a metal part; or the act of removing such a ridge; or the tool used in removing such a ridge.

BUSHING. A metal part used to line a hole, axle bearing, or similar depression. Its usual purpose is to eliminate friction or reduce wear.

BUTTOCK LINE. An edge view of a vertical plane through a body; or a reference line which is used in determining width dimensions.

CAMSHAFT. A device susceptible of rotary motion which imparts linear motion to the driven part.

CASTING. The act of pouring a material that is in the liquid state into a mold and allowing it to harden; or the object thus formed.

CATALYST. A substance used in chemical mixtures which, because of its presence, causes a quicker chemical change, although the substance itself is unaffected.

CERROMATRIX. The trade name of a metal alloy with a low melting temperature.

CENTIGRADE. A temperature scale on which zero represents the freezing point of water. Equivalent Fahrenheit temperatures for this scale will be found in the Appendix.

CHAMFER. A beveled or rounded corner or edge; or the act of producing such a corner or edge.

CHASSIS. The bottom or basic framework upon which an automobile or other type of structure is mounted.

COLD-DRAWING. The permanent deformation of a metal bar at less than its recrystallization temperature by drawing it through a die or a series of dies. This is one method of producing wire.

COLD-ROLLING. The permanent deformation of a metal at less than its recrystallization temperature by rolling. This process is often used in producing sheet metals.

COMPONENT. One of a group of important or fundamental members, qualities, or forces.

COMPOUND CONTOUR. A term used to describe structural parts which have curves in more than one plane—for example, the hood of an automobile and the cowling over an airplane engine.

COMPRESSION. A stress caused by squeezing or compressing an object.

COMPRESSION SPRING. A spring designed to react or respond to compressive forces.

COMPRESSIVE STRENGTH. The strength with which a material or structure resists *compression.*

CONCENTRICITY. A term used to describe circular objects with a common center; the antithesis of ECCENTRICITY.

CONTRACTION. The act of shrinking.

CORROSION. The deterioration of materials due to climatic conditions or immersion in water, acids, alkalies, or other elements.

COUNTERBORE. The enlargement of a hole along part of its length by boring or drilling.

COUNTERSINK. The beveling or chamfering of the end of a hole so that certain types of rivets, bolts, or similar pins may be inserted therein flush with the surface of the surrounding material.

COUNTERWEIGHT. A counterpoise, or an object designed to weigh against or counterbalance another object.

CRANE. A machine used to lift heavy loads.

CURING. The act of hardening by drying or dehydrating.

CYCLE. A period of time during which a given series of events occur.

DEFLECTION. The displacement of a part from a position it normally occupies, due to an external load.

DEOXIDIZE. To remove the oxygen from a material or substance.

DISTORTION. The state of being misshapen; or the act of twisting out of shape.

DRILL. A rotary tool for cutting cylindrical holes.

DRILL PRESS. A power-driven machine tool that holds, rotates, feeds, and withdraws drills.

DROP HAMMER. A large hammer raised by power and allowed to drop freely

so as to form metal parts which have been suitably located between the male and female parts of a die.

DUCTILITY. That property of metals which allows them to be drawn or deformed severely without breaking.

DURAL. A slang term used to denote virtually all types of aluminum alloys.

ECCENTRICITY. A term used to describe objects which do not have a common center. This is the antithesis of CONCENTRICITY.

ELECTRICAL CONDUCTIVITY. A term used to explain the extent to which various materials will conduct electricity.

ELECTRONICS. That branch of physics concerned with the phenomena of electrons, particularly those in photoelectric cells, vacuum tubes, and the like.

EMPENNAGE. The tail section of an aircraft.

EXTRUSION. A part or member which has been formed by: (1) drawing through a die in a semimolten or plastic state, or (2) by drawing cold through a set of rollers or dies.

FABRICATE. To form, frame, construct, or build.

FACING. The act of finishing or machining a surface on a material or part.

FAHRENHEIT. A temperature scale on which ice melts and water freezes at 32 degrees above zero. Equivalent centigrade temperatures for this scale will be found in the Appendix.

"FEELER." A thin blade used as a gage to determine the clearance between two members or parts.

FEMALE PART. An indented part; or a part which contains a hole. Complementary to a MALE PART.

FIBERGLAS. The trade name of a woven glass fabric.

FILAMENT. Usually a fine wire used in vacuum tubes, electric-light bulbs, and similar things. It is heated by means of an electric current which passes through the bulb or tube.

FLANGE. A web-stiffening member of an I-beam section, channel section, projections on castings for bolting, and other sections. Or a width of metal extending away from another width in a single section.

FLARING SPINNER. A power-driven tool used to flare or spread the lips of a section of tubing.

FLUX. The rate of flow or output of an electric current; or a combination of chemicals used in welding to prevent oxidization in a weld.

FOIL. A very thin leaf or plate of metal.

FORGE. To form a material (usually a metal) with pressure or repeated hammer blows while the material is in a hot or plastic condition. Parts thus formed are known as *forgings*.

FORMING. The forcing of a material to assume a desired shape.

GAGE. A tool or instrument used in taking measurements, indicating conditions, and so forth.

GAGE BLOCKS. Steel blocks finished to extreme precision, used for setting gages, micrometers, inspection fixtures, and the like.

GAS WELDING. A welding process in which a gas or combination of gases are ignited in order to provide the required heat. Acetylene and hydrogen gases are usually mixed with oxygen for welding purposes.

GAUGE. *See* GAGE.

GRAPHITE. One of the pure forms of carbon; it is used in lubricants, electric brush carbons, pigments, and other things.

GRATICULE. A transparent section of glass in a collimator or telescope. It is engraved or etched with reference lines which will enable the user of the telescope to ascertain various dimensions.

GYPSUM. A sulfate of lime, containing 21 per cent water in its liquid state. If properly treated, it is a form of plaster.

HEADSTOCK. *See* TAILSTOCK.

HEAT TREATMENT. A general term which may denote any process in which a material is heated; however, it usually refers to a process whereby metals are strengthened and refined by heating and quenching. Some typical heat-treat data are shown in the Appendix.

HEXAGONAL. Having six sides.

HUB. The center of a wheel or cylinder, through which an axle passes.

HYDRAULICS. The science concerned with the flow of fluids, especially those used to produce mechanical energy or power.

HYDROPRESS. A hydraulically operated machine often used to supply the pressure necessary in forming articles or parts.

IMPACT RESISTANCE. A term used to denote the strength with which a material resists impacts or blows.

INDUCTION HEATING. A process whereby induction coils are charged with electricity to supply the heat necessary for soldering, brazing, and other operations.

INFINITY. An unlimited extent of time, space, or quantity.

INGOT. A mass of unwrought metal; or a mass or wedge of metal cast in a mold.

IZOD IMPACT RESISTANCE. That impact resistance which is determined by means of an Izod impact test. In this test, the specimen contains a vee notch and is restrained as a cantilever beam; then an impact load is applied against the face of the notch, and impact resistance is determined by ascertaining the load under which the specimen fails.

JOHANSSON BLOCKS. A trade name, *see* GAGE BLOCKS.

KEY. A unit which positions or fastens.

KEYWAY. A groove or slot cut into a unit or part for the purpose of receiving a key.

LAMINATE. Any material which comprises plates, layers, or scales, one over the other.

LATHE. A machine tool in which a cutting bit shapes an object rotated about an axis. Material may be removed from the outside or inside surface of the work. Various devices (chuck, dog, face plate, and other means) are used to secure the material to the driving center; there may also be a dead center.

LEVELING PAD. A block or plate whose purpose is to provide a base on which some portion of a structure may be leveled.

LUBRICATION. The use of oil, grease, graphite, or other material to minimize the friction between moving parts.

MACHINABILITY. A term used in describing the ease with which a material can be machined (on a lathe, a shaper, a planer).

MALE PART. A protruding or projecting part. Complementary to a FEMALE PART.

MANUAL. Done by hand or executed by a person, in contrast to automatic or machine operations.

MASKING TAPE. A paper strip, covered on one side by a mild adhesive. It can be readily removed from any solid surface to which it is applied, and its general function is to protect that surface while a near-by area is being painted.

MELTING POINT. That point on a temperature scale at which a given material melts or becomes a liquid.

MICROMETER. A precision measuring instrument, capable of making measurements of as little as one ten-thousandth of an inch. There are a number of different types of micrometers, each designed to determine a specific type of dimension.

MICROMETRIC. An adjective used to describe instruments, tools, or parts (for example, micrometers) which can be adjusted with minute precision.

MILLING MACHINE. A machine that utilizes a circular cutting tool, known as a *milling cutter,* to finish or remove metal from a part.

MOLD. An object shaped so that it can be used in forming various materials.

MOLDABLE. An adjective used to describe any material which can be formed over or in a mold.

MODULUS OF ELASTICITY. The ratio between stresses and strains for a given material. It equals the stress in pounds per square inch divided by the deformation per inch.

MODULUS OF RUPTURE. The ultimate or breaking stress of a member in bending.

MOLTEN. Melted, or made a liquid by heat.

MORTISE. A cavity cut in a piece of wood to receive a corresponding projecting piece called a *tenon,* which has been formed on another piece of wood.

"MOUSE." A tool or instrument used in scribing lines on plaster models.

OIL ABSORPTION. A term used in designating the extent to which a material will absorb greases or oils.

OIL BOB. A weight attached to the end of a plumb line and immersed in oil. The purpose of the oil immersion is to damp the vibrations of the weight and plumb line.

OPTICAL ALIGNMENT. The act of leveling or otherwise positioning objects by means of, or with reference to, the human eye.

OPTIMUM. Best or most suitable.

ORTHOGRAPHIC. A term used to denote drawings made by projecting points on a plane by straight lines at right angles to the plane, or line drawings which give only one view of an object at a time.

OXIDIZED. A term used to describe materials which have been impregnated or combined with oxygen. Rusty iron is an oxidized material.

OXYACETYLENE. Oxygen and acetylene. Used as an adjective to describe a welding or cutting process or equipment that employs these two gases, which are mixed in the nozzle of the torch at the time of use.

PEEN. To tap lightly or burr with a peening or setting hammer.

PERPENDICULAR. The relation of two lines or parts so situated as to form an angle of 90 degrees. Commonly, a synonym for *vertical,* that is, perpendicular to the horizontal.

PHANTOM LINE. *See* Alphabet of Lines in the Appendix.

PIANO WIRE. A high-grade strand of steel whose carbon content may range from 0.8 to 1 per cent.

PILOT BUSHING. Usually a bushing which "pilots" or guides a cutting tool.

PINION GEAR. The smallest of two geared wheels.

PISTON. The sliding unit in a cylinder.

PLANE. In geometry, a surface with infinite width and length, but without thickness. It may be determined by a point and a line, two lines intersecting parallel lines, or three points.

PLUMB BOB. A weight attached to the end of a plumb line.

PLUMB LINE. A line with a weight attached to its end. It is used in making vertical or perpendicular measurements.

PNEUMATICS. That branch of physics dealing with the mechanical properties of elastic fluids, and particularly of atmospheric air.

PRECISION TOOL. An instrument or tool capable of doing extremely accurate work.

PROTOTYPE. An original or model after which anything is formed.

PULLEY. A small wheel, often with a groove cut in its circumference, over which a cable or belt passes.

QUENCHING. The quick cooling of heated metal objects by immersion in water, oil, air, or other appropriate medium.

RADIUS. The length of a straight line drawn from the center to any point on the rim of a circle.

REAM. To finish a drilled or punched hole with a reamer.

REAMER. A rotating tool with a number of cutting edges, used to finish a hole smoothly and accurately.

RECLAIMABILITY. *Same as* SALVAGEABILITY.

RE-ENTRANT. Entering in return. For example, a re-entrant angle is an angle in a polygon whose vertex is directed inward.

REPLICA. A duplicate, or an exact copy.

RESIN. An amorphous, gumlike substance. Natural resins are found in trees and plants. Synthetic resins are created in the chemical laboratory and used in making plastics.

RIGIDITY. Stiffness, or resistance to a change in form.

ROCKWELL HARDNESS. The hardness of a material, as determined by the use of a Rockwell testing machine. Some typical Rockwell readings will be found in the Appendix.

ROUTER. A machine with a rotary cutting tool for milling out the surface of wood or metal.

SALVAGEABILITY. That property which makes it possible to use a material more than once. For example, most metals may be salvaged by melting.

SANDBLASTING. A process for cleaning or scouring metals. It consists of "blasting" the metal surfaces with a high-velocity jet of fine sand and air. Besides cleaning, this blasting roughens the metal and provides an excellent base for paint.

SCRIBING. The act of marking with a pencil, pen, or steel-pointed "scriber."

SEMIMONOCOQUE. A shell structure reinforced with longerons and vertical bulkheads, but having no diagonal web members.

SHAPING. The act of cutting or shaping the edges of a sheet-metal part in accordance with the outlines of the top view of a flat pattern. This term is colloquially used as a synonym for *forming*.

SHEET. Usually a piece of material whose thickness is not greater than $\frac{1}{8}$ inch. Thicker pieces of material are more aptly termed "plates."

SHIM. Any thin strip of material that is placed between two parts of a mechanism or structure in order to produce a proper fit or alignment.

SHRINKAGE. The contraction caused by cooling. If accurate castings are to be made, molds must be dimensioned to allow for shrinkage.

SISAL FIBER. A type of hemp, obtained from plants found in Mexico and Yucatan. It is sometimes mixed with plaster to reduce the tendency of plaster castings to break.

SLEEVE. A tube into which a rod or another tube is fitted. A small sleeve may be called a THIMBLE.

SOLVENT. A fluid that is capable of dissolving solids.

SPECIFIC GRAVITY. The ratio of the weight of any substance per unit volume to the weight of water for the same unit volume. In laboratory tests to

determine specific gravity, the water usually has a temperature of 4°C., because this temperature gives a pint of water a weight of exactly 1 pound. Accordingly, if a pint of oil at 4°C. had a weight of 12 ounces, its specific gravity would be 75 per cent, or 0.75.

SPIGOT. A unit or part whose fundamental shape or function is that of a pin or peg.

SPINDLE. A rotating shaft; a pin on which the pattern of a mold may be formed.

SPOT-FACE. To remove a slight amount of material around the edges of a hole in a metal part with a tool known as a "spot facer," whose purpose is to finish the area flat. Also, a spot face may be a finished spot of a given diameter on an unfinished surface.

SQUEEGEE. A scrubber comprising a strip of rubber on the end of a handle; or a rubber-covered roller; or the act of using one of these implements.

STACK DRILLING. The act of simultaneously making identical holes through a series of sheets or plates which have been aligned and clamped together, one above the other.

STREAMLINED. A term used to describe a body which has been shaped to permit a smooth flow of air around its surfaces.

STRESS. That resultant internal force in a body which resists the tendency of an external force to change the size or shape of the body; or the resultant internal force that resists strain.

STRIPPER. That portion of an automatic riveting machine whose fundamental function is to punch rivet holes in the work.

STUD. A headless bolt or screw; when inserted in a threaded hole, it has a threaded projecting end.

SUBVISUAL. Too small to be seen by the naked eye.

SUPERSTRUCTURE. Any structure built on something else; or anything erected on a foundation or basis.

SWARF. Filings or scraps, produced when a material is machined.

SYMMETRY. A condition which exists when two or more parts of a structure have the same appearance, size, weight, and other similar characteristics.

TACK WELD. A temporary, incomplete weld. Its purpose is to hold two or more parts together until a finished job of welding can be accomplished.

TAILSTOCK. The member of a lathe which slides along the bed. It holds the dead center, in contradistinction to the HEADSTOCK, which holds the spindle.

TAP. A tool for cutting threads in a hole; or the act of using such a tool.

TEMPLATE. A pattern.

TENON. A male part, made from wood and designed to fit into a MORTISE.

TENSILE STRENGTH. The strength with which a material resists forces that tend to stretch or elongate.

THERMAL. Pertaining to, determined by, or measured by heat.

THERMOPLASTIC. One of the two physical types of plastics. Materials of this type can be repeatedly softened by heat. (*See* THERMOSETTING PLASTIC.)

THERMOSETTING PLASTIC. One of the two physical types of plastics. Materials of this type become infusible when they have once been heated and hardened. (*See* THERMOPLASTIC.)

THIMBLE. A cylindrical unit used to join the ends of tubes, pipes, shafting, and so forth. Or a small SLEEVE.

TIMING CYCLE. The interval during which an operation is timed with reference to a watch or clock.

TRANSIT. An optical instrument used in measuring horizontal angles or lines.

TRANSVERSE. Lying across, or in a crosswise direction.

TRIM. To cut to a given size or shape.

TURNBUCKLE. A hollow, threaded cylinder used for tightening or adjusting the tension of cables or wires. The cable or wire is attached to eye bolts, forks, or swaged fittings which can be screwed into the threaded ends of the cylinder until the desired tension is attained.

UNILATERAL. One-sided.

UNIVERSAL. A term used to describe those things which can be widely used or applied.

VALVE. Any device by which the flow of liquid, air, or any loose material in bulk may be started, stopped, or regulated by a movable part which opens or obstructs passage.

VENT. A small aperture leading out of or into some enclosed space; or any small hole or opening which serves as a passageway for fluids such as water and air.

WARP. To turn or twist out of shape or out of a straight direction, by contraction.

WARPAGE. The act or degree of warping.

WATER LINE. An edge view of a horizontal plane through a body; or a reference line used in determining height dimensions.

WEARING SURFACE. A surface designed to resist wear.

WEIGHT. A measure of the force exerted on a body due to the pull of gravity.

WELD. A joint made by welding.

WELDING. The fusing together of metal parts by heating them to a plastic state and pressing or hammering them together, or by heating them to the molten state through the use of flame or electricity.

YOKE. A unit which couples, connects, or binds together other units or parts.

ZINC CHROMATE. A heavy, yellowish paste ($ZnCrO_4$). It is most commonly used as a pigment for primers and as a sealing compound for airtight and watertight structures.

APPENDIX

Tool Symbols

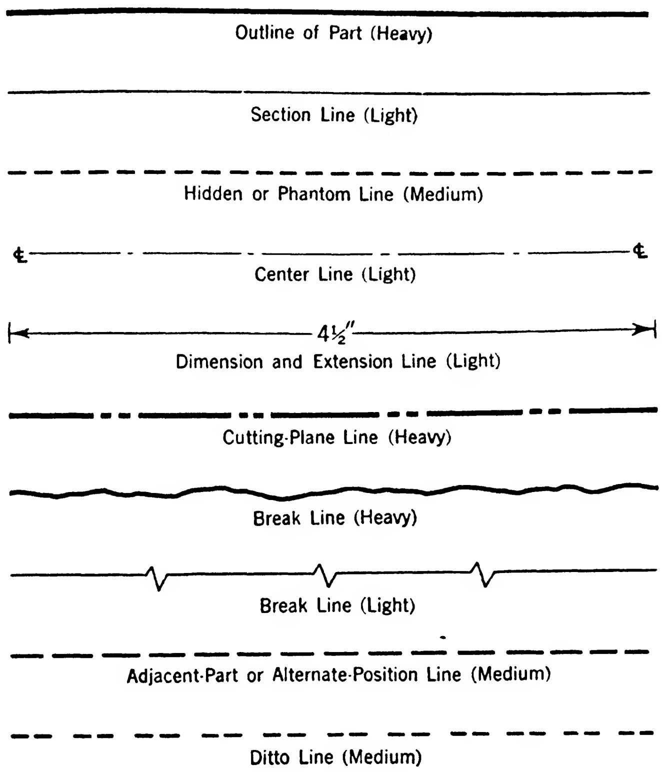
Since there are no standard symbols or abbreviations for tools, the following are presented merely as a guide for those manufacturers who do not yet have their own tool-identification codes. The authors believe that these symbols are superior to others now in use because they are comparatively brief and easy to remember.

AEFX—Assembly (Erco) Fixture
AIMO—Air Mold
ASFX—Assembly Fixture
ASTO—Assembly Tool
BDDI—Beading Die
BEFM—Bending Form
BHFX—Broaching Fixture
BITO—Burnishing Tool
BKDI—Brake Die
BLDI—Blanking Die
BOBR—Boring Bar
BOFX—Boring Fixture
BUCU—Burring Cutter
CACD—Clean-up Cradle
CBCU—Counterbore Cutter
CCJW—Chuck Jaws
CETO—Cleaning Tool
CKFM—Checking Form
CKGA—Checking Gage
CKTP—Checking Template
CLAD—Collet Adapter
CNDI—Combination Die
CNFX—Combination Fixture
CPBR—Clamp Bar
CPVS—Clamping Vise
CRRL—Contouring Rolls
CSCU—Countersink Cutter
CTTO—Centering Tool
CUPL—Cutting Pliers
CUSK—Cutting Sketch
DATO—Disassembly Tool
DHDI—Drop-hammer Die
DKDI—Dinking Die
DRAD—Drill Adapter
DRBG—Drill Bushing
DRCC—Drill Chuck
DRFX—Drill Fixture
DRGD—Drill Guard
DRHE—Drill Head
DRJI—Drill Jig
DRPE—Drill Plate
DRSH—Drill Shell
DRTP—Drill Template
ELAN—Electrical Analyzer
EXBH—External Broach
EXGA—External Gage
FLDI—Flare Die
FMDI—Form Die
FMMD—Forming Mandrel
FMRL—Forming Rolls
FMTO—Form Tool
GPPL—Gripping Pliers
GRFX—Grinding Fixture
HACD—Handling Cradle
HATO—Handling Tool
HLCU—Hole Cutter
HLDI—Hole Die
HNFM—Hand Form
HNSR—Hand Shears

HPFM—Hydropress Form
HTFX—Heat-treat Fixture
IDHE—Index Head
INGA—Inspection Gage
ITBH—Internal Broach
ITGA—Internal Gage
JGDI—Joggle Die
JGSM—Joggle Shims
MCAC—Machine Accessory
MCAR—Machining Arbor
MITP—Miniature Template
MKTP—Mark Template
MLCU—Mill Cutter
MLFX—Milling Fixture
MPBR—Multipunch Bar
MPDI—Multipunch Die
MPPE—Multipunch Template
MSGA—Master Gage
MSLO—Master Layout
MSPE—Master Plate
MSSE—Master Sample
MSTP—Master Template
NHDI—Notch Die
NOTO—Numbering Tool
PCDI—Pierce Die
PCSH—Pierce Shell
PCTP—Pierce Template
PDDR—Production Drill
PDMU—Production Mock-up
PDPA—Production Pattern
PDSE—Production Sample
PFFX—Profiling Fixture
PRSE—Proof Sample
RGTP—Rough Template
RPTO—Repairing Tool
RTCU—Router Cutter
RTFM—Router Form
RTTP—Router Template
RVBR—Riveting Bar
RVSJ—Riveting Set
RVSZ—Riveting Squeezer
SAFX—Saw Fixture
SAJI—Saw Jig
SFPE—Surface Plate
SGDI—Swaging Die
SLDI—Slot Die
SPMC—Special Machine
SSCU—Spot-face Cutter
SSFX—Spot-face Fixture
STFM—Stretcher Form
STJW—Stretcher Jaws
SVDV—Screw Driver
SWAC—Spot-weld Accessory
SWFX—Spot-weld Fixture
SXRM—Straight Reamer
TAFX—Tapping Fixture
TAHE—Tapping Head
TBSA—Tubular Saw
TERM—Taper Reamer
THDI—Thread Die
THGA—Thread Gage
THTA—Thread Tap
TOAC—Tool Accessory
TODC—Tooling Dock
TODT—Tool Detail
TOFM—Tooling Form
TOGA—Tooling Gage
TOLO—Tooling Layout
TOPA—Tooling Pattern
TOPE—Tooling Plate
TOSE—Tooling Sample
TOTO—Tooling Tool
TOTP—Tooling Template
TQWR—Torque Wrench
TRDI—Trim Die
TRSH—Trim Shell
TRTP—Trim Template
TSTO—Testing Tool
TUCA—Turning Cam
TUFX—Turning Fixture
TUWR—Turning Wrench
VSJW—Vise Jaws
WLFX—Welding Fixture
WPFM—Wiping Form

Alphabet of Lines

The use of these lines in connection with engineering drawings has been approved by the American Standards Association and numerous other engineering organizations.



Hardness Conversion Table *

(For hardened steel and hard alloys)

Rockwell Hardness Tester, Brale penetrator			Rockwell Superficial, N Brale diamond penetrator [a]						
C scale, 150-kg load	A scale, 60-kg load	D scale, 100-kg load	15-N scale, 15-kg load	30-N scale, 30-kg load	45-N scale, 45-kg load	Diamond pyramid,[b] 10-kg load	Brinell,[c] 3,000-kg load	Rockwell hardness tester, Ball penetrator,[d] G scale 150-kg load	Tensile strength, 1,000 lb./in.[2]
80	92.0	86.5	96.5	92.0	87.0	1,865	General conversion values on material harder than about C-70 on the Rockwell Hardness Tester will probably be long in dispute because as yet there are few materials hard enough to be brought into that study and because some of those few do not flow nicely under the testing load but have a tendency to crumble, and others do not approach homogeneity.		Inexact and only for steel
79	91.5	85.5	—	91.5	86.5	1,787			
78	91.0	84.5	96.0	91.0	85.5	1,710			
77	90.5	84.0	—	90.5	84.5	1,633			
76	90.0	83.0	95.5	90.0	83.5	1,556			
75	89.5	82.5	—	89.0	82.5	1,478			
74	89.0	81.5	95.0	88.5	81.5	1,400			
73	88.5	81.0	—	88.0	80.5	1,323			
72	88.0	80.0	94.5	87.0	79.5	1,245			
71	87.0	79.5	—	86.5	78.5	1,160			
70	86.5	78.5	94.0	86.0	77.5	1,076			
69	86.0	78.0	93.5	85.0	76.5	1,004			
68	85.5	77.0	—	84.5	75.5	942			
67	85.0	76.0	93.0	83.5	74.5	894			
66	84.5	75.5	92.5	83.0	73.0	854			
65	84.0	74.5	92.0	82.0	72.0	820			
64	83.5	74.0	—	81.0	71.0	789			
63	83.0	73.0	91.5	80.0	70.0	763			
62	82.5	72.5	91.0	79.0	69.0	739	—	—	—
61	81.5	71.5	90.5	78.5	67.5	716	—	—	—
60	81.0	71.0	90.0	77.5	66.5	695	614	—	314
59	80.5	70.0	89.5	76.5	65.5	675	600	—	306
58	80.0	69.0	—	75.5	64.0	655	587	—	299
57	79.5	68.5	89.0	75.0	63.0	636	573	—	291
56	79.0	67.5	88.5	74.0	62.0	617	560	—	284
55	78.5	67.0	88.0	73.0	61.0	598	547	—	277
54	78.0	66.0	87.5	72.0	59.5	580	534	—	270
53	77.5	65.5	87.0	71.0	58.5	562	522	—	263
52	77.0	64.5	86.5	70.5	57.5	545	509	—	256
51	76.5	64.0	86.0	69.5	56.0	528	496	—	250

50	76.0	63.0	85.5	68.5	55.0	513	484	—	243
49	75.5	62.0	85.0	67.5	54.0	498	472	—	236
48	74.5	61.5	84.5	66.5	52.5	485	460	—	230
47	74.0	60.5	84.0	66.0	51.5	471	448	—	223
46	73.5	60.0	83.5	65.0	50.0	458	437	—	217
45	73.0	59.0	83.0	64.0	49.0	446	426	—	211
44	72.5	58.5	82.5	63.0	48.0	435	415	—	205
43	72.0	57.5	82.0	62.0	46.5	424	404	—	199
42	71.5	57.0	81.5	61.5	45.5	413	393	—	194
41	71.0	56.0	81.0	60.5	44.5	403	382	—	188
40	70.5	55.5	80.5	59.5	43.0	393	372	—	182
39	70.0	54.5	80.0	58.5	42.0	383	362	—	177
38	69.5	54.0	79.5	57.5	41.0	373	352	—	171
37	69.0	53.0	79.0	56.5	39.5	363	342	—	166
36	68.5	52.5	78.5	56.0	38.5	353	332	—	162
35	68.0	51.5	78.0	55.0	37.0	343	322	—	157
34	67.5	50.5	77.0	54.0	36.0	334	313	—	153
33	67.0	50.0	76.5	53.0	35.0	325	305	—	148
32	66.5	49.0	76.0	52.0	33.5	317	297	—	144
31	66.0	48.5	75.5	51.5	32.5	309	290	—	140
30	65.5	47.5	75.0	50.5	31.5	301	283	92.0	136
29	65.0	47.0	74.5	49.5	30.0	293	276	91.0	132
28	64.5	46.0	74.0	48.5	29.0	285	270	90.0	129
27	64.0	45.5	73.5	47.5	28.0	278	265	89.0	126
26	63.5	44.5	72.5	47.0	26.5	271	260	88.0	123
25	63.0	44.0	72.0	46.0	25.5	264	255	87.0	120
24	62.5	43.0	71.5	45.0	24.0	257	250	86.0	117
23	62.0	42.5	71.0	44.0	23.0	251	245	84.5	115
22	61.5	41.5	70.5	43.0	22.0	246	240	83.5	112
21	61.0	41.0	70.0	42.5	20.5	241	235	82.5	110
20	60.5	40.0	69.5	41.5	19.5	236	230	81.0	108

a The 15-N, 30-N, and 45-N values are in scales of the Rockwell Superficial Hardness Tester, a specialized form of Rockwell Tester, having lighter loads and more sensitive depth reading system, used where for one or another reason the indentation must be exceptionally shallow.

b Four-sided, 136°. Measurement of 2 diagonals by microscope. Hardness numbers computed by formula.

c Standard type, Hultgren 10-mm. Ball penetrator.

d 1/16".

Standard Dimensions for Nuts and Bolts.

Diameter	No. of Threads per Inch	Diameter at Root of Thread	Diameter of Tap Drill	Area in Sq. Inches		Tensile Strength at Stress of 6000 Pounds per Sq. Inch	Dimensions of Nuts and Bolt Heads				
				Of Bolt	At Root of Thread						
1/4	20	0.185	13/64	0.049	0.026	160	1/2	0.578	0.707	1/4	1/4
5/16	18	0.240	1/4	0.076	0.045	270	19/32	0.686	0.840	5/16	19/64
3/8	16	0.294	5/16	0.110	0.068	410	11/16	0.794	0.972	3/8	11/32
7/16	14	0.345	23/64	0.150	0.093	560	25/32	0.902	1.105	7/16	25/64
1/2	13	0.400	27/64	0.196	0.126	760	7/8	1.011	1.237	1/2	7/16
9/16	12	0.454	15/32	0.248	0.162	1,000	31/32	1.119	1.370	9/16	31/64
5/8	11	0.507	17/32	0.307	0.202	1,210	1 1/16	1.227	1.502	5/8	17/32
3/4	10	0.620	41/64	0.442	0.302	1,810	1 1/4	1.444	1.768	3/4	5/8
7/8	9	0.731	3/4	0.601	0.419	2,520	1 7/16	1.660	2.033	7/8	23/32
1	8	0.838	55/64	0.785	0.551	3,300	1 5/8	1.877	2.298	1	13/16
1 1/8	7	0.939	31/32	0.994	0.694	4,160	1 13/16	2.093	2.563	1 1/8	29/32
1 1/4	7	1.064	1 3/32	1.227	0.893	5,350	2	2.310	2.828	1 1/4	1
1 3/8	6	1.158	1 7/32	1.485	1.057	6,340	2 3/16	2.527	3.093	1 3/8	1 3/32
1 1/2	6	1.283	1 11/32	1.767	1.295	7,770	2 3/8	2.743	3.358	1 1/2	1 3/16
1 5/8	5 1/2	1.389	1 27/64	2.074	1.515	9,090	2 9/16	2.960	3.623	1 5/8	1 9/32
1 3/4	5	1.490	1 17/32	2.405	1.746	10,470	2 3/4	3.176	3.889	1 3/4	1 3/8
1 7/8	5	1.615	1 21/32	2.761	2.051	12,300	2 15/16	3.393	4.154	1 7/8	1 15/32
2	4 1/2	1.711	1 49/64	3.142	2.302	13,800	3 1/8	3.609	4.419	2	1 9/16
2 1/4	4 1/2	1.961	2 1/64	3.976	3.023	18,100	3 1/2	4.043	4.949	2 1/4	1 3/4
2 1/2	4	2.175	2 15/64	4.909	3.719	22,300	3 7/8	4.476	5.479	2 1/2	1 15/16
2 3/4	4	2.425	2 31/64	5.940	4.620	27,700	4 1/4	4.909	6.010	2 3/4	2 1/8
3	3 1/2	2.629	2 11/16	7.069	5.428	32,500	4 5/8	5.342	6.540	3	2 5/16
3 1/4	3 1/2	2.879	2 15/16	8.296	6.510	39,000	5	5.775	7.070	3 1/4	2 1/2
3 1/2	3 1/4	3.100	3 11/64	9.621	7.548	45,300	5 3/8	6.208	7.600	3 1/2	2 11/16
3 3/4	3	3.317	3 3/8	11.045	8.641	51,800	5 3/4	6.641	8.131	3 3/4	2 7/8
4	3	3.567	3 5/8	12.566	9.963	59,700	6 1/8	7.074	8.661	4	3 1/16
4 1/4	2 7/8	3.798	3 27/32	14.186	11.340	68,000	6 1/2	7.508	9.191	4 1/4	3 1/4
4 1/2	2 3/4	4.028	4 3/32	15.904	12.750	76,500	6 7/8	7.941	9.721	4 1/2	3 7/16
4 3/4	2 5/8	4.255	4 5/16	17.721	14.215	85,500	7 1/4	8.374	10.252	4 3/4	3 5/8
5	2 1/2	4.480	4 9/16	19.635	15.760	94,000	7 5/8	8.807	10.782	5	3 13/16
5 1/4	2 1/2	4.730	4 13/16	21.648	17.570	105,500	8	9.240	11.312	5 1/4	4
5 1/2	2 3/8	4.953	5 1/32	23.758	19.260	116,000	8 3/8	9.673	11.842	5 1/2	4 3/16
5 3/4	2 3/8	5.203	5 9/32	25.967	21.250	127,000	8 3/4	10.106	12.373	5 3/4	4 3/8
6	2 1/4	5.423	5 1/2	28.274	23.090	138,000	9 1/8	10.539	12.903	6	4 9/16

Electrode Size and Machine Setting for Aluminum Metallic-arc Welds

Thickness (inch)	Electrode diameter (inch)	Amperes	Rods per pound
0.064	1/8	45–55	32
0.081	1/8	55–65	32
0.102	1/8	65–75	32
0.125	1/8	75–85	32
5/32	1/8 or 5/32	85–100	32–23
3/16	5/32	100–125	23
1/4	5/32 or 3/16	125–175	23–17
5/16	3/16	175–225	17
3/8	1/4	225–300	10.5

Machine Settings for Spot-welding Aluminum Alloys

Gage		Time cycles	Current amperes	Electrode pressure	
B & S no.	Inch			Min. lb.	Max. lb.
26	0.016	4	14,000	200	400
24	0.020	6	16,000	300	500
22	0.025	6	17,000	300	500
20	0.032	8	18,000	400	600
18	0.040	8	20,000	400	600
16	0.051	10	22,000	500	700
14	0.064	10	24,000	500	700
12	0.081	12	28,000	600	800
10	0.102	12	32,000	800	1000
8	0.128	15	35,000	800	1200

Torch Tip Sizes for Gas-welding

Metal thickness B & S gage	Oxyhydrogen			Oxyacetylene		
	Diam. of orifice in tip inch	Oxygen pressure (lb./sq. in.)	Hydrogen pressure (lb./sq. in.)	Diam. of orifice in tip inch	Oxygen pressure (lb./sq. in.)	Acetylene pressure (lb./sq. in.)
24–22	0.035	1	1	0.025	1	1
20–18	0.045	1	1	0.035	1	1
16–14	0.065	2	1	0.055	2	2
12–10	0.075	2	1	0.065	3	3
1/8–3/16	0.095	3	2	0.075	4	4
1/4	0.105	4	2	0.085	5	5
5/16	0.115	4	2	0.085	5	5
3/8	0.125	5	3	0.095	6	6
5/8	0.150	8	6	0.105	7	7

Conditions for Heat Treatment of Aluminum Alloys

Alloy	Solution heat treatment				Precipitation heat treatment		
	Temperature (°F.)	Approximate time of heating [a]	Quench [b]	Temper designation	Temperature (°F.)	Time of aging	Temper designation
17S	930–950	—	Cold water	—	Room	4 days [c]	17S-T
A17S	930–950	—	Cold water	—	Room	4 days [c]	A17S-T
24S	910–930	—	Cold water	—	Room	4 days [c]	24S-T
53S	960–980	—	Cold water	53S-W	315–325 or 345–355	18 hours 8 hours	53S-T
61S	960–980	—	Cold water	61S-W	315–325 or 345–355	18 hours 8 hours	61S-T

[a] In a molten nitrate bath, the time varies from 10 to 60 minutes, depending upon the size of the load and the thickness of the material. In an air furnace, proper allowance must be made for a slower rate of bringing the load up to temperature. For heavy material a longer time at temperature may be necessary.

[b] It is essential that the quench be made with a minimum time loss in transfer from the furnace.

[c] More than 90 per cent of the maximum properties are obtained during the first day of aging.

[d] Precipitation heat-treatment at elevated temperatures is patented.

Approximate Machine Settings for Seam-welding Aluminum Alloys

Alloy	Thickness (inch)	Pressure (lb.)	Cycles		Spots per inch	Approx. "On" RMS amperes
			On	Off		
52S-½H	0.025	600	1	6½	18.0	26,000
52S-½H	0.032	680	1	6½	16.0	29,000
52S-½H	0.040	760	1	6½	14.3	32,000
52S-½H	0.051	855	1½	6	12.6	36,000
52S-½H	0.064	960	1½	6	11.3	37,500
52S-½H	0.072	1015	1½	6	10.6	39,000
52S-½H	0.081	1080	2	11½	10.0	40,000
52S-½H	0.102	1210	2	11½	9.0	42,500

For 52S-¼H, reduce pressure 10%; for 52S-O, reduce pressure 25%; for 3S-½H, reduce pressure 25%.

Standards for Wire Gages Used in the United States

Number of wire gage	American or Brown & Sharpe	Birmingham or Stubs' iron wire	Washburn & Moen, Worcester, Mass.	W. & M. steel music wire	American S. & W. Co.'s music wire gage	Imperial wire gage	Stubs' steel wire	U. S. standard gage for sheet and plate iron and steel
00000000	—	—	—	.0083	—	—	—	—
0000000	—	—	—	.0087	—	—	—	—
000000	—	—	—	.0095	.004	.464	—	.46875
00000	—	—	—	.010	.005	.432	—	.4375
0000	.460	.454	.3938	.011	.006	.400	—	.40625
000	.40964	.425	.3625	.012	.007	.372	—	.375
00	.3648	.380	.3310	.0133	.008	.348	—	.34375
0	.32486	.340	.3065	.0144	.009	.324	—	.3125
1	.2893	.300	.2830	.0156	.010	.300	.227	.28125
2	.25763	.284	.2625	.0166	.011	.276	.219	.265625
3	.22942	.259	.2437	.0178	.012	.252	.212	.250
4	.20431	.238	.2253	.0188	.013	.232	.207	.234375
5	.18194	.220	.2070	.0202	.014	.212	.204	.21875
6	.16202	.203	.1920	.0215	.016	.192	.201	.203125
7	.14428	.180	.1770	.023	.018	.176	.199	.1875
8	.12849	.165	.1620	.0243	.020	.160	.197	.171875
9	.11443	.148	.1483	.0256	.022	.144	.194	.15625
10	.10189	.134	.1350	.027	.024	.128	.191	.140625
11	.090742	.120	.1205	.0284	.026	.116	.188	.125
12	.080808	.109	.1055	.0296	.029	.104	.185	.109375
13	.071961	.095	.0915	.0314	.031	.092	.182	.09375
14	.064084	.083	.0800	.0326	.033	.080	.180	.078125
15	.057068	.072	.0720	.0345	.035	.072	.178	.0703125
16	.05082	.065	.0625	.036	.037	.064	.175	.0625
17	.045257	.058	.0540	.0377	.039	.056	.172	.05625
18	.040303	.049	.0475	.0395	.041	.048	.168	.050
19	.03589	.042	.0410	.0414	.043	.040	.164	.04375
20	.031961	.035	.0348	.0434	.045	.036	.161	.0375
21	.028462	.032	.03175	.046	.047	.032	.157	.034375
22	.025347	.028	.0286	.0483	.049	.028	.155	.03125
23	.022571	.025	.0258	.051	.051	.024	.153	.028125
24	.0201	.022	.0230	.055	.055	.022	.151	.025
25	.0179	.020	.0204	.0586	.059	.020	.148	.021875
26	.01594	.018	.0181	.0626	.063	.018	.146	.01875
27	.014195	.016	.0173	.0658	.067	.0164	.143	.0171875
28	.012641	.014	.0162	.072	.071	.0149	.139	.015625
29	.011257	.013	.0150	.076	.075	.0136	.134	.0140625
30	.010025	.012	.0140	.080	.080	.0124	.127	.0125
31	.008928	.010	.0132	—	.085	.0116	.120	.0109375
32	.00705	.009	.0128	—	.090	.0108	.115	.01015625
33	.00708	.008	.0118	—	.095	.0100	.112	.009375
34	.006304	.007	.0104	—	—	.0092	.110	.00859375
35	.005614	.005	.0095	—	—	.0084	.108	.0078125
36	.005	.004	.0090	—	—	.0076	.106	.00703125
37	.004453	—	—	—	—	.0068	.103	.006640625
38	.003965	—	—	—	—	.0060	.101	.00625
39	.003531	—	—	—	—	.0052	.099	—
40	.003144	—	—	—	—	.0048	.097	—

Drill Sizes

Size	Decimal equivalent	Size	Decimal equivalent	Size	Decimal equivalent	Size	Decimal equivalent
1/2	.5000	G	.2610	23	.1540	1/16	.0625
31/64	.4844	F	.2570	24	.1520	53	.0595
15/32	.4687	E1/4	.2500	25	.1495	54	.055
29/64	.4531	D	.2460	26	.1470	55	.0520
7/16	.4375	C	.2420	27	.1440	3/64	.0469
27/64	.4219	B	.2380	9/64	.1406	56	.0465
Z	.4130	15/64	.2344	28	.1405	57	.0430
13/32	.4062	A	.2340	29	.1360	58	.0420
Y	.4040	1	.2280	30	.1285	59	.0410
X	.3970	2	.2210	1/8	.1250	60	.0400
25/64	.3906	7/32	.2187	31	.1200	61	.0390
W	.3860	3	.2130	32	.1160	62	.0380
V	.3770	4	.2090	33	.1130	63	.0370
3/8	.3750	5	.2055	34	.1110	64	.0360
U	.3680	6	.2040	35	.1100	65	.0350
23/64	.3594	13/64	.2031	7/64	.1094	66	.0330
T	.3580	7	.2010	36	.1065	67	.0320
S	.3480	8	.1990	37	.1040	1/32	.0313
11/32	.3437	9	.1960	38	.1015	68	.0310
R	.3390	10	.1935	39	.0995	69	.0292
Q	.3320	11	.1910	40	.0980	70	.0280
21/64	.3281	12	.1890	41	.0960	71	.0260
P	.3230	3/16	.1875	3/32	.0937	72	.0250
O	.3160	13	.1850	42	.0935	73	.0240
5/16	.3125	14	.1820	43	.0890	74	.0225
N	.3020	15	.1800	44	.0860	75	.0210
19/64	.2969	16	.1770	45	.0820	76	.0200
M	.2950	17	.1730	46	.0810	77	.0180
L	.2900	11/64	.1719	47	.0785	78	.0160
9/32	.2812	18	.1695	5/64	.0781	1/64	.0156
K	.2810	19	.1660	48	.0760	79	.0145
J	.2770	20	.1610	49	.0730	80	.0135
I	.2720	21	.1590	50	.0700		
H	.2660	22	.1570	51	.0670		
17/64	.2656	5/32	.1562	52	.0635		

Screw Thread and Tap Drill Sizes

(Tap drills allow approximately 75 per cent full thread.)

	Size of tap	Threads per inch	Tap drill	Body drill
NC or A.S.M.E. special machine screws.	1	64	53	47
	2	56	50	42
	3	48	47	37
	4	40	43	31
	5	40	38	29
	6	32	36	27
	8	32	29	18
	10	24	25	9
	12	24	16	2
NF or A.S.M.E. standard machine screws.	2	64	50	42
	3	56	45	37
	4	48	42	31
	5	44	37	29
	6	40	33	27
	8	36	29	18
	10	32	21	9
	10 [a]	30	22	9
	12	28	14	2
NPT[b] pipe threads.	1/8	27	R	—
	1/4	18	7/16	—
	3/8	18	37/64	—
	1/2	14	23/32	—
	3/4	14	59/64	—
	1	11 1/2	1 5/32	—
	1 1/4	11 1/2	1 1/2	—
	1 1/2	11 1/2	1 47/64	—
	2	11 1/2	2 7/32	—
	2 1/2	8	2 5/8	—
	3	8	3 1/4	—
NF or S.A.E. standard screws.	1/4	28	3	—
	5/16	24	I	—
	3/8	24	Q	—
	7/16	20	25/64	—
	1/2	20	29/64	—
	9/16	18	33/64	—
	5/8	18	37/64	—
	11/16 [c]	16	5/8	—
	3/4	16	11/16	—
	7/8	14	13/16	—
	1	14	15/16	—
	1 1/8	12	1 3/64	—

[a] A.S.M.E. only.
[b] American national taper pipe thread.
[c] S.A.E. only.

Heat-treatment Procedure for Structural Steels

Steel no.	Temperatures (°F.)			Quenching medium 65°F.	Tempering (drawing) temperatures for tensile strength (°F.)				
	Normalizing air cool	Annealing	Hardening		100,000 (lb./in.²)	125,000 (lb./in.²)	150,000 (lb./in.²)	180,000 (lb./in.²)	200,000 (lb./in.²)
1020	1,650–1,750	1,600–1,700	1,575–1,675	Water	—	—	—	—	—
X1020	1,650–1,750	1,600–1,700	1,575–1,675	Water	—	—	—	—	—
1025	1,600–1,700	1,575–1,650	1,575–1,675	Water	(a)	—	—	—	—
1035	1,575–1,650	1,575–1,625	1,525–1,600	Water	875	—	—	—	—
1045	1,550–1,600	1,550–1,600	1,475–1,550	Oil or Water	1,150	—	—	—	—
1095	1,475–1,550	1,450–1,500	1,425–1,500	Oil	(b)	—	1,100	850	750
2330	1,475–1,525	1,425–1,475	1,450–1,500	Oil or Water	1,100	950	800	—	—
3135	1,600–1,650	1,500–1,550	1,475–1,525	Oil	1,250	1,050	900	750	650
3140	1,600–1,650	1,500–1,550	1,475–1,525	Oil	1,325	1,075	925	775	700
X4130	1,600–1,700	1,525–1,575	1,575–1,625	Oil[c]	(d)	1,050	900	700	575
4140	1,600–1,650	1,525–1,575	1,525–1,575	Oil	1,350	1,100	1,025	825	675
4150	1,550–1,600	1,475–1,525	1,500–1,550	Oil	—	1,275	1,175	1,050	950
X4340	1,550–1,625	1,525–1,575	1,475–1,550	Oil	—	1,200	1,050	950	850
4640	1,675–1,700	1,525–1,575	1,500–1,550	Oil	—	1,200	1,050	750	625
6135	1,600–1,700	1,550–1,600	1,575–1,625	Oil	1,300	1,075	950	800	750
6150	1,600–1,650	1,525–1,575	1,550–1,625	Oil	(d e)	1,200	1,000	900	800
6195	1,600–1,650	1,525–1,575	1,500–1,550	Oil	(f)	—	—	—	—
30905	—	(g h)	(i)	—	—	—	—	—	—
51210	1,525–1,575	1,525–1,575	1,775–1,825[j]	Oil	1,200	1,100	(k)	750	—
51335	—	1,525–1,575	1,775–1,850	Oil	—	—	—	—	1,070
52100	1,625–1,700	1,400–1,450	1,525–1,550	Oil	(f)	—	—	—	—
Corrosion resisting (16–2)[l] . .	—	—	—	—	—	—	—	—	—
Silicon chromium (for springs) . .	—	—	1,700–1,725	Oil	(m)	—	—	—	—

[a] Draws at 1150°F. for tensile strength of 70,000 lb. per sq. in.

[b] For spring temper, draw at 800°F. to 900°F. Rockwell hardness C–40–45.

[c] Bars or forgings may be quenched in water from 1500°F. to 1600°F.

[d] Air-cooling from the normalizing temperature will produce a tensile strength of approximately 90,000 lb. per sq. in.

[e] For spring temper, draw at 850° F. to 950°F. Rockwell hardness C–40–45.

[f] Draw at 350°F. to 450°F. to remove quenching strains. Rockwell hardness C–60–65.

[g] Anneal at 1600°F. to 1700°F. to remove residual stresses due to welding or cold work. May be applied only to steel containing titanium or columbium.

[h] Anneal at 1900°F. to 2100°F. to produce maximum softness and corrosion resistance. Cool in air or quench in water.

[i] Hardened by cold work only.

[j] Lower side of range for sheet 0.06 inch and under. Middle of range for sheet and wire 0.125 inch. Upper side of range for forgings.

[k] Not recommended for intermediate tensile strengths because of low impact.

[l] As desired, subject to the approval of the government. Request for approval shall be accompanied by a report of tests, conducted in the presence of the inspector, and showing results in conformance with the requirements of Specification AN–QQ–S–770. Results shall consist of complete tests on each of three sets of specimens. Refer to section G, paragraph entitled "Heat Treatment of Steel AN–QQ–S–770."

[m] Draw at approximately 800°F. and cool in air for Rockwell hardness of C–50.

Allowances for Fits

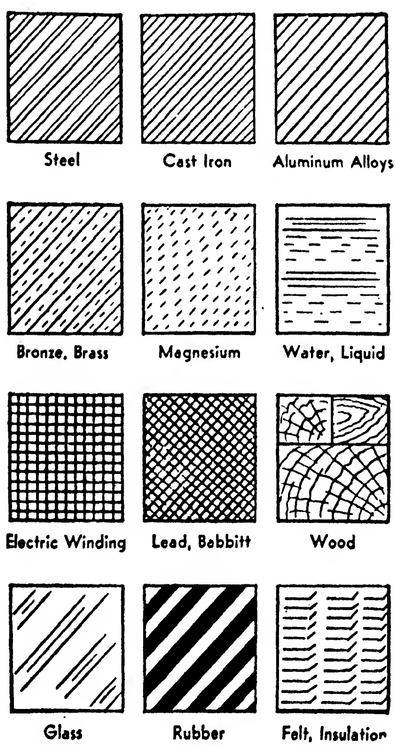
These allowances are for average machine work. For long bearings, the running fit allowances may have to be increased.

Diameter (inches)	Running fits	Push fits	Driving fits	Forced fits
Up to ½	−0.00075 to −0.0015	−0.00025 to −0.00075	+0.0004 to +0.0006	+0.0005 to +0.001
½ to 1	−0.001 to −0.002	−0.0005 to −0.001	+0.0005 to +0.001	+0.001 to +0.003
1 to 2	−0.0015 to −0.0025	−0.0005 to −0.0015	+0.00075 to +0.002	+0.002 to +0.004
2 to 3	−0.0015 to −0.003	−0.0005 to −0.0015	+0.0015 to +0.003	+0.003 to +0.006
3 to 4	−0.002 to −0.0035	−0.00075 to −0.002	+0.002 to +0.004	+0.005 to +0.008
4 to 5	−0.0025 to −0.004	−0.00075 to −0.002	+0.002 to +0.0045	+0.006 to +0.010
5 to 6	−0.0025 to −0.0045	−0.00075 to −0.002	+0.003 to +0.005	+0.008 to +0.012

Composition and Uses of Principal Brasses and Bronzes

Material	Composition (%)						Uses
	Copper	Tin	Lead	Iron	Zinc	Phosphorus	
Naval brass or tobin bronze.	60	0.50-1.50	0.30	0.10	—	—	Bolts, turnbuckles, machine products.
Brass sheet..........	64-67	—	0.30	0.05	—	—	Oil strainers.
Manganese bronze....	53-62	—	0.15	—	38-47	—	Sand castings.
Leaded gun metal....	86-89	9-11	1.00-2.50	—	—	0.25	Bushings.
Phosphor bronze wire.	93-95	4-6	0.10	—	20	0.03-0.40	Flat or wire springs.

Common Symbols Used to Denote Materials in Mechanical Drawing.



Factors for Computing Shrinkage Fit Allowances

These factors are for solid shafts and may be used in connection with the following formula:

$$A=\frac{T(2+C)}{30{,}000{,}000}$$

In this formula, A is the allowance per inch of diameter, T is the true tangential tensile stress at inner surface of outer member, and C is the factor obtained from this table. The values of ratio C are for solid steel shafts of nominal diameter D_1, and for hubs of steel or cast iron of nominal external and internal diameters of D_2 and D_1, respectively.

Ratio of Diameters $\frac{D_2}{D_1}$	Steel hub	Cast-iron hub	Ratio of diameters $\frac{D_2}{D_1}$	Steel hub	Cast-iron hub
1.5	0.227	0.234	2.8	0.410	0.432
1.6	0.255	0.263	3.0	0.421	0.444
1.8	0.299	0.311	3.2	0.430	0.455
2.0	0.333	0.348	3.4	0.438	0.463
2.2	0.359	0.377	3.6	0.444	0.471
2.4	0.380	0.399	3.8	0.450	0.477
2.6	0.397	0.417	4.0	0.455	0.482

Metric System of Measurements

Length—Meter : Mass—Gram : Capacity—Liter

At 4°C. (39.2°F.), 1 cubic decimeter or 1 liter of water equals 1 kilogram.

$$1000\text{ milli}\left\{\begin{matrix}\text{meters (mm)}\\\text{grams (mg)}\\\text{liters (ml)}\end{matrix}\right\}=100\text{ centi}\left\{\begin{matrix}\text{meters (cm)}\\\text{grams (cg)}\\\text{liters (cl)}\end{matrix}\right\}=10\text{ deci}\left\{\begin{matrix}\text{meters (dm)}\\\text{grams (dg)}\\\text{liters (dl)}\end{matrix}\right\}=1\left\{\begin{matrix}\text{meter (m)}\\\text{gram (g)}\\\text{liter (l)}\end{matrix}\right.$$

$$1000\left\{\begin{matrix}\text{meters}\\\text{grams}\\\text{liters}\end{matrix}\right\}=100\text{ deca}\left\{\begin{matrix}\text{meters (dkm)}\\\text{grams (dkg)}\\\text{liters (dkl)}\end{matrix}\right\}=10\text{ hecto}\left\{\begin{matrix}\text{meters (hm)}\\\text{grams (hg)}\\\text{liters (hl)}\end{matrix}\right\}=1\text{ kilo}\left\{\begin{matrix}\text{meter (km)}\\\text{gram (kg)}\\\text{liter (kl)}\end{matrix}\right.$$

1 metric ton = 1000 kilograms
100 square meters = 1 are (ar)
100 ares = 1 hectare (har)
100 hectares = 1 square kilometer

Decimal Equivalents of Fractions of an Inch

Fraction					Decimal equivalent	Fraction					Decimal equivalent	Fraction					Decimal equivalent
4ths	8ths	16ths	32nds	64ths		4ths	8ths	16ths	32nds	64ths		4ths	8ths	16ths	32nds	64ths	
				1/64	0.015 625				11/32		0.343 75					43/64	0.671 875
			1/32		0.031 25					23/64	0.359 375			11/16			0.687 5
				3/64	0.046 875		3/8				0.375					45/64	0.703 125
		1/16			0.062 5					25/64	0.390 625				23/32		0.718 75
				5/64	0.078 125				13/32		0.406 25					47/64	0.734 375
			3/32		0.093 75					27/64	0.421 875	3/4					0.750
				7/64	0.109 375			7/16			0.437 5					49/64	0.765 625
	1/8				0.125					29/64	0.453 125				25/32		0.781 25
				9/64	0.140 625				15/32		0.468 75					51/64	0.796 875
			5/32		0.156 25					31/64	0.484 375			13/16			0.812 5
				11/64	0.171 875	1/2					0.500					53/64	0.828 125
		3/16			0.187 5					33/64	0.515 625				27/32		0.843 75
				13/64	0.203 125				17/32		0.531 25					55/64	0.859 375
			7/32		0.218 75					35/64	0.546 875		7/8				0.875
				15/64	0.234 375			9/16			0.562 5					57/64	0.890 625
1/4					0.250					37/64	0.578 125				29/32		0.906 25
				17/64	0.265 625				19/32		0.593 75					59/64	0.921 875
			9/32		0.281 25					39/64	0.609 375			15/16			0.937 5
				19/64	0.296 875		5/8				0.625					61/64	0.953 125
		5/16			0.312 5					41/64	0.640 625				31/32		0.968 75
				21/64	0.328 125				21/32		0.656 25					63/64	0.984 375

Weights and Specific Gravities

Substance	Weight (lb./cu. ft.)	Specific gravity
Metals, alloys, and ores		
Aluminum, cast, hammered	165	2.55–2.75
Aluminum, bronze	481	7.7
Brass, cast, rolled	534	8.4–8.7
Bronze, 7.9 to 14% Sn	509	7.4–8.9
Copper, cast, rolled	556	8.8–9.0
Copper ore, pyrites	262	4.1–4.3
Gold, cast, hammered	1205	19.25–19.3
Iron, cast, pig	450	7.2
Iron, wrought	485	7.6–7.9
Iron, steel	490	7.8–7.9
Iron, spiegel-eisen	468	7.5
Iron, ferro-silicon	437	6.7–7.3
Iron ore, hematite	325	5.2
Iron ore, hematite in bank	160–180	—
Iron ore, hematite loose	130–160	—
Iron ore, limonite	237	3.6–4.0
Iron ore, magnatite	315	4.9–5.2
Iron slag	172	2.5–3.0
Lead	710	11.37
Lead ore, galena	465	7.3–7.6
Manganese	475	7.2–8.0
Manganese ore, pyrolusite	259	3.7–4.6
Mercury	849	13.6
Nickel	565	8.9–9.2
Nickel, monel metal	556	8.8–9.0
Platinum, cast, hammered	1330	21.1–21.5
Silver, cast, hammered	656	10.4–10.6
Tin, cast, hammered	459	7.2–7.5
Tin ore, cassiterite	418	6.4–7.0
Zinc, cast, rolled	440	6.9–7.2
Zinc ore, blende	253	3.9–4.2
Timber (U. S. seasoned *)		
Ash, white, red	40	0.62–0.65
Cedar, white, red	22	0.32–0.38
Chestnut	41	0.00
Cypress	30	0.48
Fir, Douglas spruce	32	0.51
Fir, eastern	25	0.40
Elm, white	45	0.72
Hemlock	29	0.42–0.52
Hickory	49	0.74–0.84
Locust	46	0.73
Maple, hard	43	0.68
Maple, white	33	0.53
Oak, chestnut	54	0.86
Oak, live	59	0.95
Oak, red, black	41	0.65
Oak, white	46	0.74
Pine, Oregon	32	0.51
Pine, red	30	0.48
Pine, white	26	0.41
Pine, yellow, long-leaf	44	0.70
Pine, yellow, short-leaf	38	0.61
Poplar	30	0.48
Redwood, California	26	0.42
Spruce, white, black	27	0.40-0.46
Walnut, black	38	0.61
Walnut, white	26	0.41

* Moisture content by weight: seasoned timber, 15 to 20 per cent; green timber, up to 50 per cent.

General Mathematical Rules

To find circumference—			
Multiply diameter by	3.1416	Or divide diameter by	0.3183
To find diameter—			
Multiply circumference by	0.3183	Or divide circumference by	3.1416
To find radius—			
Multiply circumference by	0.15915	Or divide circumference by	6.28318
To find side of an inscribed square—			
Multiply diameter by	0.7071		
Or multiply circumference by	0.2251	Or divide circumference by	4.4428
To find side of an equal square—			
Multiply diameter by	0.8862	Or divide diameter by	1.1284
Or multiply circumference by	0.2821	Or divide circumference by	3.545

Square—

A side multiplied by	1.4142	equals diameter of its circumscribing circle.
A side multiplied by	4.443	equals circumference of its circumscribing circle.
A side multiplied by	1.128	equals diameter of an equal circle.
A side multiplied by	3.547	equals circumference of an equal circle.
Square inches multiplied by	1.273	equal circle inches of an equal circle.

To find the area of a circle—

Multiply circumference by ¼ diameter.

Or multiply the square of diameter by	0.7854
Or multiply the square of circumference by	.07958
Or multiply the square of ½ diameter by	3.1416

To find the surface of a sphere or globe—

Multiply the diameter by the circumference.

Or multiply the square of diameter by	3.1416
Or multiply four times the square of radius by	3.1416

To find the weight of brass and copper sheets, rods, and bars—

Ascertain the number of cubic inches in piece and multiply same by weight per cubic inch.

Brass, 0.2972

Copper, 0.3212

Or multiply the length by the breadth (in feet) and product by weight in pounds per square foot.

Centigrade and Fahrenheit Temperature Equivalents

Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.
0	32.0	26	78.8	52	125.6	78	172.4
1	33.8	27	80.6	53	127.4	79	174.2
2	35.6	28	82.4	54	129.2	80	176.0
3	37.4	29	84.2	55	131.0	81	177.8
4	39.2	30	86.0	56	132.8	82	179.6
5	41.0	31	87.8	57	134.6	83	181.4
6	42.8	32	89.6	58	136.4	84	183.2
7	44.6	33	91.4	59	138.2	85	185.0
8	46.4	34	93.2	60	140.0	86	186.8
9	48.2	35	95.0	61	141.8	87	188.6
10	50.0	36	96.8	62	143.6	88	190.4
11	51.8	37	98.6	63	145.4	89	192.2
12	53.6	38	100.4	64	147.2	90	194.0
13	55.4	39	102.2	65	149.0	91	195.8
14	57.2	40	104.0	66	150.8	92	197.6
15	59.0	41	105.8	67	152.6	93	199.4
16	60.8	42	107.6	68	154.4	94	201.2
17	62.6	43	109.4	69	156.2	95	203.0
18	64.4	44	111.2	70	158.0	96	204.8
19	66.2	45	113.0	71	159.8	97	206.6
20	68.0	46	114.8	72	161.6	98	208.4
21	69.8	47	116.6	73	163.4	99	210.2
22	71.6	48	118.4	74	165.2	100	212.0
23	73.4	49	120.2	75	167.0		
24	75.2	50	122.0	76	168.8		
25	77.0	51	123.8	77	170.6		

To convert Fahrenheit to Centigrade, subtract 32, multiply by 5 and divide by 9.
To convert Centigrade to Fahrenheit, multiply by 9, divide by 5 and add 32.

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